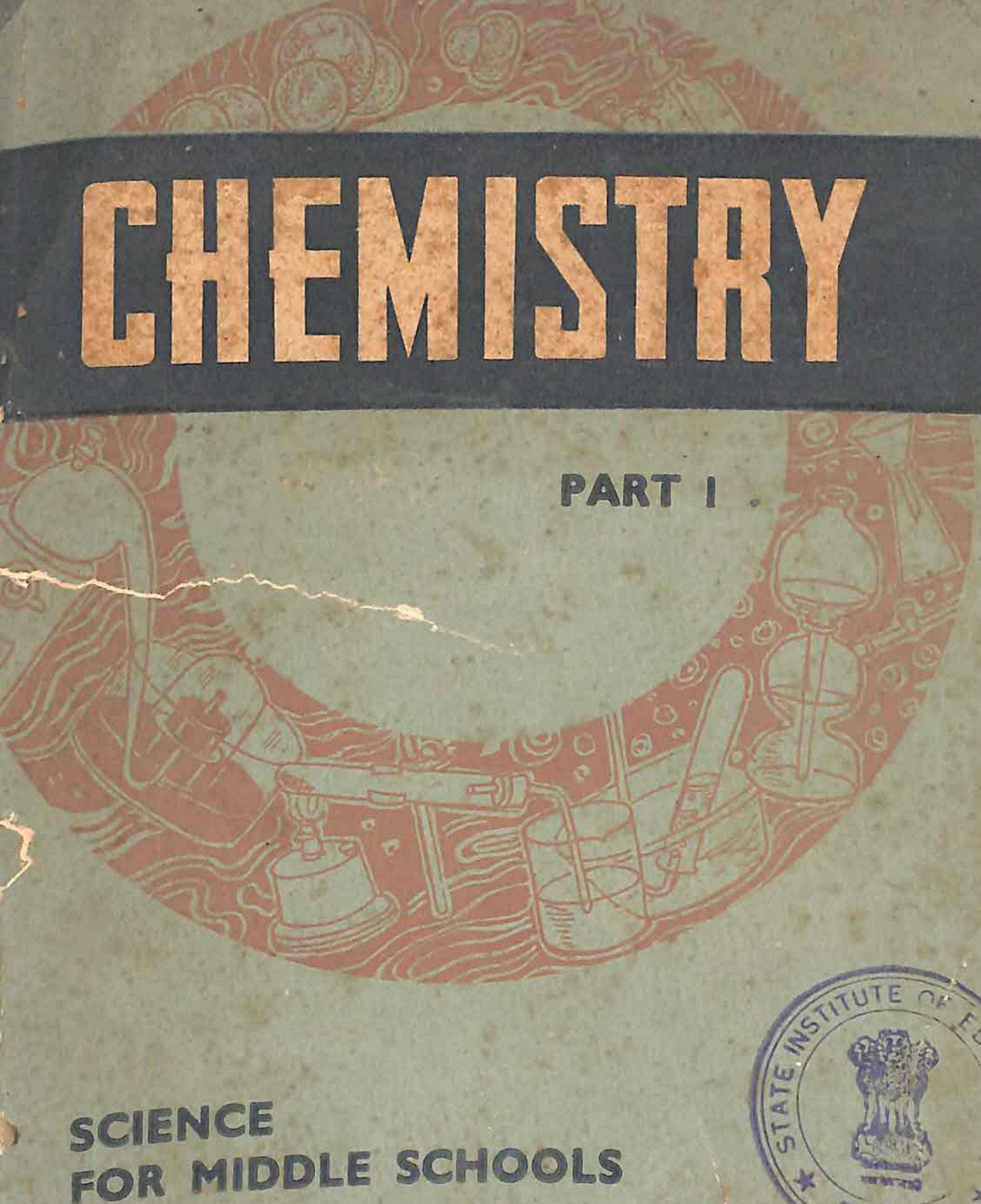
CHEMISTRY

PART I



STATE INSTITUTE OF EDUCATION
BANIPUR

SCIENCE
FOR MIDDLE SCHOOLS

NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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CHEMISTRY

PART I

Science for Middle Schools

NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

June 1968
Jaisatha 1890

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No. 8534

CHEMISTRY
PART I
Board of Writers

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Foreword

There is today a ferment in science education. The rapid developments in science and technology in recent years have made it necessary to think of changes in curriculum, textbooks and methods of teaching science in our schools. While this is generally true of all countries in the world, it is more so for India, if we wish to bridge the distance which separates us from the advanced countries. Unless our pupils in the schools learn more science and better science, it will not be possible for them to help the country in developing at a faster rate. But to do this in the same time span of ten or eleven years in the school, it is necessary to think of new ways of teaching science. If a scientific attitude has to develop, its base must be built on conceptual understanding and reasoning rather than on retention and reproduction of bits of information.

Science in some form or the other, either as General Science or as Everyday Science, is being taught in all our schools at the middle stage. It has, however, been felt by all concerned that this is far from adequate, as it does not provide a firm foundation for the understanding of basic concepts of physics, chemistry and biology. The Education Commission (1964-66) has observed that "the general science approach to the teaching of science which has been very widely adopted at the elementary stage during the last 10 years has not proved successful as it tends to make science appear somewhat formless and without structure and runs counter to its methodology. A disciplined approach to science learning would, it is felt, be more effective in providing the necessary scientific base to the young pupils."

The UNESCO Planning Mission which visited this country in 1964 also made similar recommendations for effecting improvements in the teaching of science and mathematics in Indian schools. Following these recommendations, the Department of Science Education in the National Council of Educational Research and Training has undertaken a major project to upgrade science and mathematics teaching starting from the middle school stage. A new curriculum in science and mathematics for the middle stage as separate disciplines of physics, chemistry, biology and mathematics has been prepared and textbooks, teachers' guides and curriculum guides are being developed. It is expected that this curriculum would equip those who leave school at the close of the middle stage with enough basic knowledge of the sciences and its applications. The middle stage covers three years of school education. All the materials developed under this project are being tried out in selected schools and

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The National Council is grateful to UNESCO experts who assisted the Department of Science Education on this project. It is also thankful to the Director of Education, Delhi Administration, who very kindly provided facilities to try out the curricular materials in selected schools in Delhi. The National Council will welcome comments and suggestions from teachers and others interested in science education for the improvement of these materials.

New Delhi
20 January, 1968

SHIB K. MITRA
Joint Director,
National Council of Educational Research and Training

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STATE INSTITUTE OF EDUCATION

CHAPTER I

Substances and the Changes that Take Place in Them

1. What is Chemistry ?

All of you must have heard the words 'Science' and 'Chemistry'. In this book we will try to study this special branch of science called Chemistry. It helps us to understand about the nature of things and the changes that take place in them. By the help of this knowledge we can also change materials in various ways and prepare new substances. It is due to this that the role of chemistry is getting more and more important in our national economy. Many metals are used in our daily life for various purposes. Extraction of these metals from their ores requires a knowledge of chemistry. Plastics and synthetic fibres are now finding more and more use in our lives. It is chemistry that made possible the discovery and manufacture of these artificial substances which have not only replaced many naturally occurring substances but have also improved upon them in many cases. Chemical fertilizers increase the yield of crops, insecticides and pesticides protect the plant from diseases and pests. Many of the modern wonder drugs are also the products of chemistry. In other words, in every sphere of human activity, whether it may be the food that we eat or the clothes that we wear, chemistry plays an important part.

We find around us many objects such as glass tumblers, wooden chairs and tables, iron and rubber tubings, earthenware, etc. These are all *physical bodies.*

Such physical bodies may be similar or dissimilar in their form, size, mass and colour, etc. Another important factor that determines similarity or the difference between physical bodies is their compostion—the material of which they are made. For example, a looking glass, tumbler, bottle, window-pane, etc. are all made of glass. The one thing that is common in all the physical objects is the matter (glass) of which they are made though they are different in shape and size (Fig. 1).

Again, several objects, though similar in form and dimensions, can be made of different materials, for example, a pipe may be made of glass or plastic or a metal like iron or copper, etc. (Fig. 2).

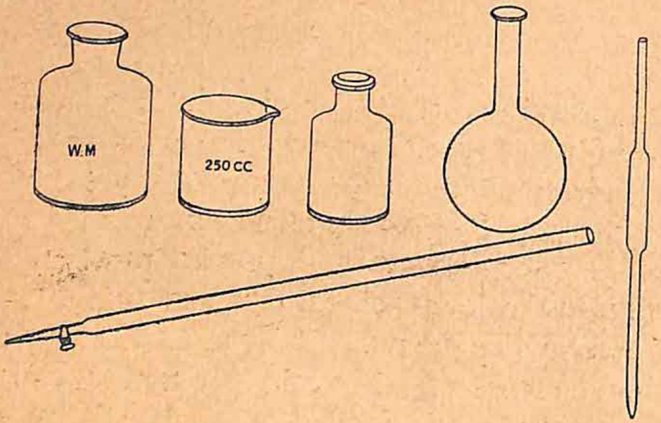


FIG. 1. Different objects made of one substance

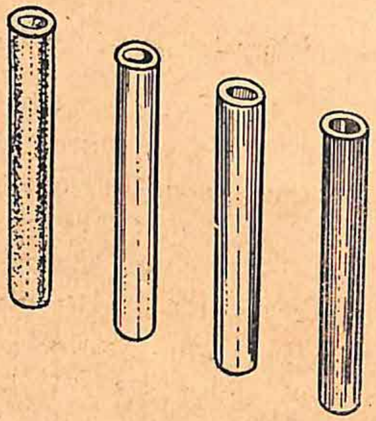


FIG. 2. Objects similar in form and dimensions, made of different substances

The matter of which a physical body is made is known as a **substance**.

Iron, sand, stone, glass, water, copper, plastics, etc. are all examples of different substances. The number of substances known to us at present is more than two million and new additions are being made every day by chemists. For example, until recently plastics was almost an unknown substance but to day it finds use in almost every sphere of human activity. Owing to the large and ever increasing number of these substances, it is not possible to enumerate them.

Many substances are found in nature. Chemists have produced in laboratories many other substances which do not occur naturally.

Different objects can be made from one and the same substance but the chemist is not interested in studying the shape and the form of these objects. His main interest is to study the substances which make these objects and the properties of these substances.

QUESTIONS AND EXERCISES

1. What is a substance ?
2. Name some of the substances you use in your everyday life. Do you use any objects made of plastics ? If so, give their names.
3. What substances are used in your home for killing mosquitoes and for killing germs in the drains by the health authorities ?

2. Molecular Structure of Substances

All substances are made up of very small particles called molecules. Molecules are very minute in size and weight. It is impossible to see them even with the most powerful microscope in your school. Molecules of some substances have, however, been photographed by an instrument called 'electron microscope'.

Even a very small quantity of any substance, for example, one gram of water, contains as many as 33,000,000,000,000,000,000,000 molecules of water. This is so big a number that counting at the rate of 1,000 molecules per minute will take us about sixty billion years to count the total.

Though a substance may appear to be compact from outward appearance, there are wide gaps (*interstices*) between molecules, which may expand or contract. The change in the distances between molecules explains the expansion or contraction of the bodies on heating or cooling. We can demonstrate the expansion of bodies on heating by a simple experiment as follows :

A round-bottomed flask fitted with a one-holed cork is filled with coloured water. A long glass tube is inserted through the cork. On heating the flask carefully, water rises in the tube. On cooling, the level of the water again falls down (Fig. 3).

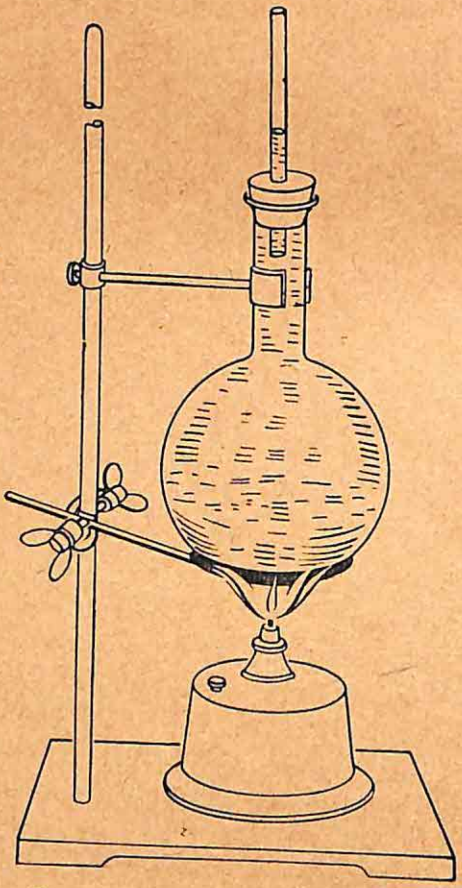


FIG. 3. Expansion of water on heating

Between molecules there are forces of attraction and repulsion. These forces of attraction and repulsion are not uniform. Thus in solid substances, molecules are held together strongly and do not separate easily which shows that the force of attraction is greater than the force of repulsion. In gaseous substances, however, the force of repulsion is greater than that of attraction and hence the molecules get separated from one another.

If you open a bottle of strong scent or ether the smell of the contents pervades the atmosphere of the whole room and every student in the class will feel it. Why is it so ?

Molecules remain in constant motion. The molecules of different substances do not move with the same speed. It depends upon the weight of the molecule. The speed of a lighter molecule is greater than that of a heavier one. This can be demonstrated as follows :

Take two small china dishes and put a few drops of bromine into each of them. Cover one of the dishes with a glass cylinder full of hydrogen and the other with that filled with air (Fig. 4). It will be seen that the vapours of bromine and hydrogen get mixed with each other more quickly than the vapours of bromine and air. This is explained on the basis of the fact that molecules of hydrogen, which is the lightest of all gases, move four times as fast as the molecules of the gases present in the air.

Take a jar half filled with water. Fit a separating funnel containing alcohol, coloured red, so that the tip of its tail almost reaches the bottom of the jar. Allow a few drops of the coloured alcohol into the jar. Observe how the colour gradually spreads evenly throughout the water in the jar (Fig. 5).

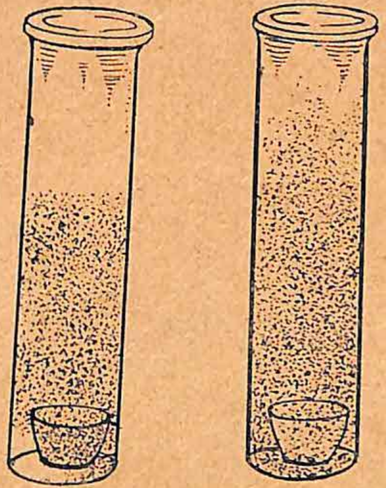


FIG. 4. Vapours of bromine spread quicker in the cylinder containing hydrogen (right) than in the cylinder containing air (left)

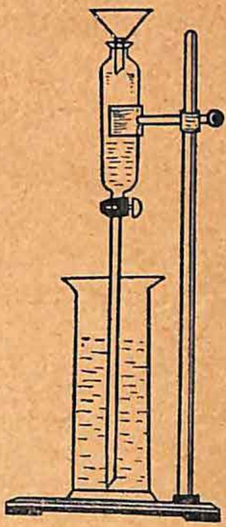


FIG. 5. A separating funnel

Intermingling of molecules of a substance with those of other substances is called **diffusion**.

It has been found that with the increase of temperature the speed of the molecules also increases. The molecules move faster at higher temperatures and push one another with greater force so that the distances between them increase. This explains why all bodies expand on heating. For example, when we heat a solid substance up to its melting point, the substance changes to liquid state because the force of attraction between the molecules diminishes. In liquids the molecules are held together less firmly and hence they get separated from one another easily. This explains the evaporation of some liquids even at low temperatures.

All the molecules of a given substance are identical, but they are different from those of the other substances in weight, dimensions and in many other respects. You will learn more about the structure of molecules when you study chemistry at an advanced level.

PRACTICAL EXERCISES

Do the following exeperiments at home and make your own observations.

Place a couple of sugar cubes at the bottom of a glass tumbler (in case sugar cubes are not available two lumps of common salt may be used) and carefully fill it with water up to the top. Take out a little water by a spoon from the top layer without disturbing the tumbler and taste it. It is sweet (or salty as the case may be)? Cover the mouth of the tumbler by a suitable lid and allow it to stand for a day. Taste the water from the upper layer as before. What do you observe now? Let the tumbler stand for another day and then see what the taste is. How much time is needed for the layer to turn sweet (or salty)? How do you explain this behaviour?

QUESTIONS AND EXERCISES

1. How will you show that molecules are in constant motion?
2. What is diffusion? Give some examples. Can you cite any example of diffusion from your daily life?
3. Explain what happens when :
   (a) water evaporates in the open air.
   (b) smell of the cooking of vegetables or the burning of milk spreads in the neighbourhood.

3. Properties of Substances

Every substance has certain properties. By comparison of the qualities of various substances it can be said whether a given substance is similar to or different from any other substance.

Water, when pure, is a *transparent* liquid. It has no *taste*, *colour* or *odour*. Petrol and spirit are also colourless but these liquids can be distinguished between themselves and from water by means of smell. Petrol and spirit are *inflammable* whereas water extinguishes fire.

Sugar and common salt are two colourless *crystalline* solids, heavier than water. When put in a vessel full of water, they sink to its bottom. They are also *soluble* in water and give it a sweet or a saline taste. They are *brittle*.

All of you probably know what copper is. It is a solid substance having a dull red colour. A piece of copper sinks but does not dissolve in water. A piece of copper can be beaten by a hammer into thin plates. This shows that copper is *malleable*. Copper can also be drawn up into long wires showing that it is *ductile* too. Copper is also used for making electric wires as it is a good *conductor* of electricity.

Aluminium is a solid substance having a silvery white colour. It is lighter than copper though heavier than water. It is also a good conductor of electricity. Thus, aluminium and copper are two solid substances which are different from sugar and common salt. While the former two substances are malleable and ductile the latter are brittle.

Air is another substance which is different from all the substances mentioned above (copper, aluminium, sugar and salt). It has neither colour nor odour.

> *The qualities on the basis of which we can establish similarities and dissimilarities between various substances are called* **properties of substances**.

In properties of substances we may include physical state (solid, liquid, gaseous), colour, lustre, smell, hardness, ability to conduct electricity and heat, ability to burn, malleability, ductility and several other qualities. Specific gravity, boiling and melting points are some of the other qualities which are included in properties.

The similarities and differences between various substances depend upon the properties of molecules of which substances are made. Some of the properties can be observed from the outward appearance of a substance, while the others can be determined by carrying out certain tests.

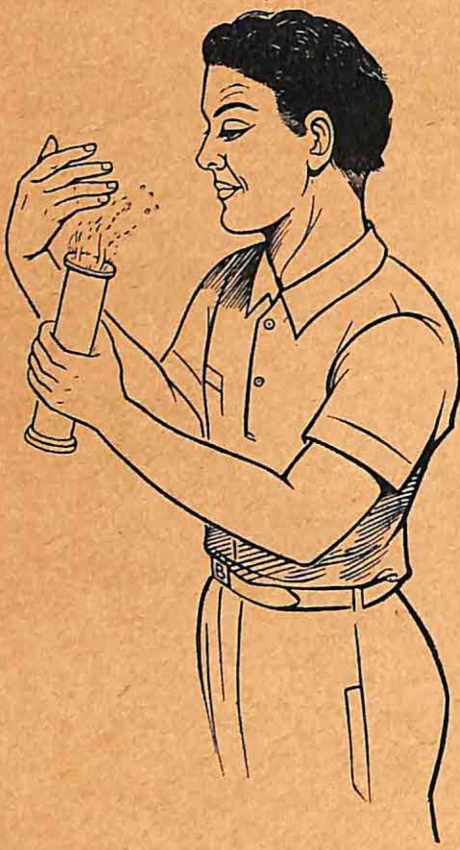


FIG. 6. The right way of smelling an unknown substance

The odour of a substance can be determined by smelling it. But one should be very cautious while smelling an unkown substance because it may be pungent like spirit or may be poisonous like chlorine (Fig. 6).

One should not taste any unknown substance. It might be poisonous. Certain substances have a harmful effect on the skin and are likely to cause burns, boils, etc.

Some properties of the substances may be approximately determined by making use of the sense organs. For accurate determinations one has to make use of the measuring instruments.

To know how many times a given substance is heavier than water, it is necessary to determine its *specific gravity*. The specific gravity of a substance is defined as the ratio of the mass of the substance to the mass of the same volume of water. The specific gravity of a liquid can be determined by an apparatus known as hydrometer. (Fig. 7).

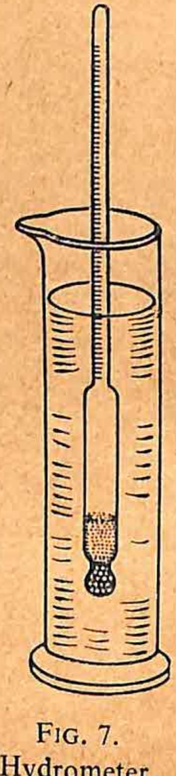


FIG. 7. Hydrometer

The *boiling point* of a liquid can be determined by the use of a thermometer. The apparatus shown in Fig. 8 is used to determine the boiling point of water.

The liquid whose boiling point is to be determind is taken in a tube which is fitted with a cork carrying a thermometer. The bulb of the thermometer is kept above the level of the liquid and is surrounded by the vapours of the liquid when heated. A hole is made in the cork to allow vapours of the liquid to escape. The test-tube is then heated till the liquid starts boiling and the thermometer shows a constant temperature. This temperature is recorded and is called the boiling point of the liquid.

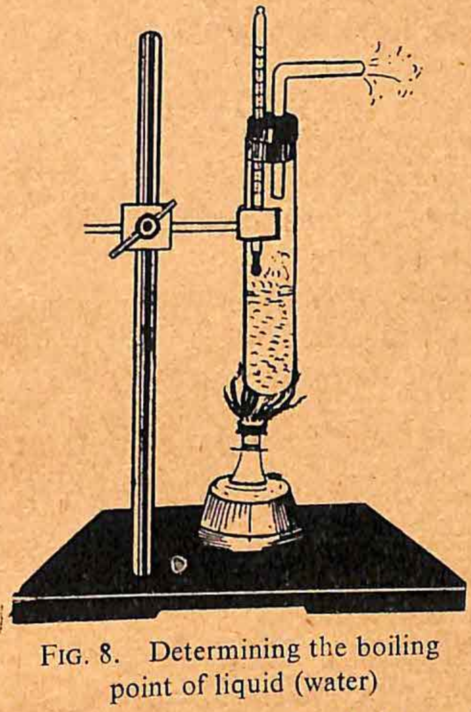


FIG. 8. Determining the boiling point of liquid (water)

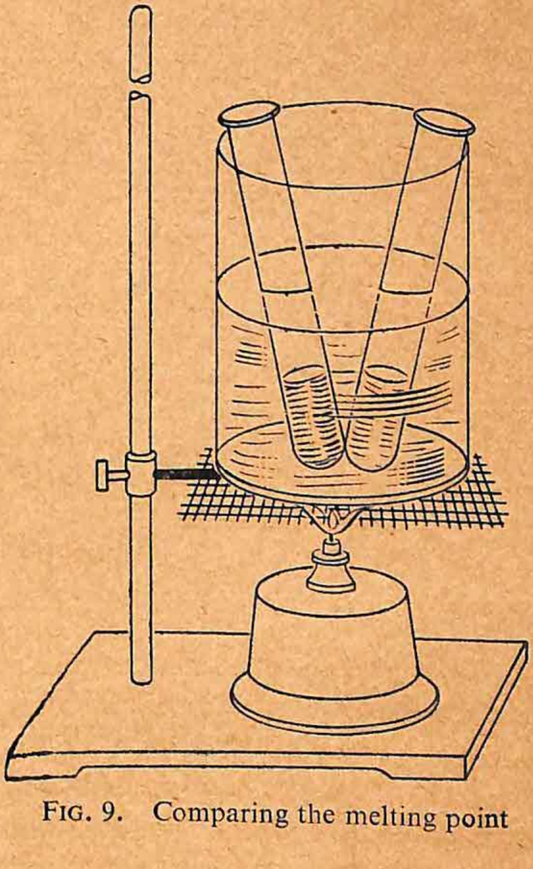


FIG. 9. Comparing the melting point

It has been found that substances have a definite temperature at which they melt. For example, if we place two test-tubes, one containing sulphur and the other wax, in a beaker half filled with water and heat the beaker, it is noted that wax melts while sulphur does not, even when the water starts boiling. Now if the test-tube containing sulphur is taken out and heated it is found that sulphur also melts after some time. This shows that wax melts at a temperature below the boiling point of water while sulphur melts at a temperature higher than the boiling point of water (Fig. 9).

Melting point of substances can be determined with the help of a thermometer. For example, we can determine the melting point of ice by dipping the bulb of the thermometer in melting ice. The melting point is found to be 0°C.

For determining the melting point of substances, like iron, which have a high melting point, we shall have to make use of certain other instruments. It has been found that some substances like wood do not melt at all. They get cracked or charred. Sugar, starch and rubber are some more examples of substances which do not melt.

QUESTIONS AND EXERCISES

1. State what is meant by properties of substances.
2. How can you distinguish salt from chalk, kerosene from water ? What are the common properties of these substances ?
3. Name the properties of glass, charcoal and iron.
4. Give the names of any two gaseous substances known to you.
5. State how you will determine the boiling point of a liquid.
6. What precautions should be observed while smelling an unknown substance ?

LABORATORY WORK

Exercise I : *Proper handling of laboratory equipment*

Before starting your work, read the following rules carefully and observe them strictly.

1. Keep the place where you work clean.

2. Do not spill solutions or scatter substances all over the place. In case a reagent is spilled accidentally, remove it at once according to the advice of your teacher. All waste meterials like pieces of paper, match sticks, etc. should be thrown into the dustbin.
3. Do not taste any substance. Do not eat or drink in laboratory vessels.
4. Observe all the precautions while smelling an unknown substance.
5. While handling the reagents care should be taken that these do not come in contact with the skin or clothes.
6. Be careful when you are working with fire. In case something catches fire, try to extinguish it by throwing sand on it or by covering it with a blanket.
7. While heating a test-tube containing a liquid take care that its mouth is not directed towards you or your neighbours. The liquid may spurt out and cause burns. You should not lean over a vessel containing a boiling liquid for the same reason.
8. In case an accident (*e.g.*, a cut or a burn) takes place, use the first-aid box.
9. Clean all the apparatus before you leave the laboratory after finishing your day's work.

A. Proper handling of a spirit lamp

1. Study the construction of a spirit lamp and explain the significance of its various parts. Draw a diagram of a sprit lamp in your notebook.
2. Fill the spirit lamp with spirit using a funnel. After moistening the outer end of the wick with the spirit put it in its proper place and cover it with the cap.
3. For lighting the spirit lamp, remove the cap and apply a lighted match-stick or a burning splinter to the wick. The lamp can be extinguished by covering the flame of the spirit lamp with the cap.

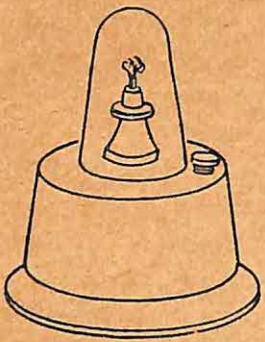


FIG. 10. A spirit lamp

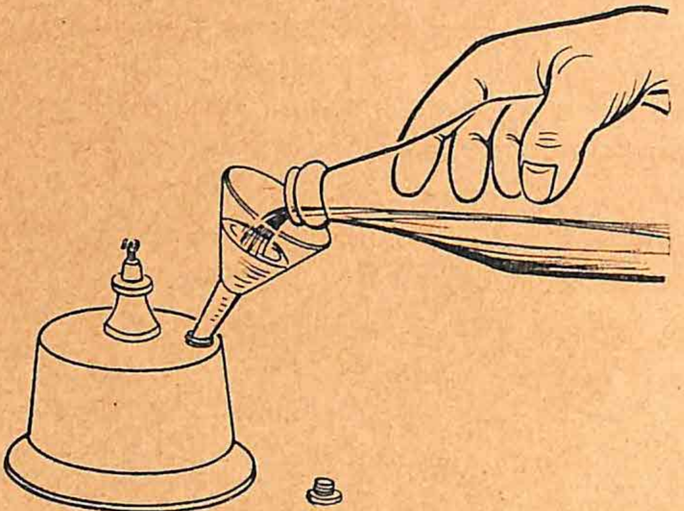


FIG. 11. Filling a spirit lamp with spirit

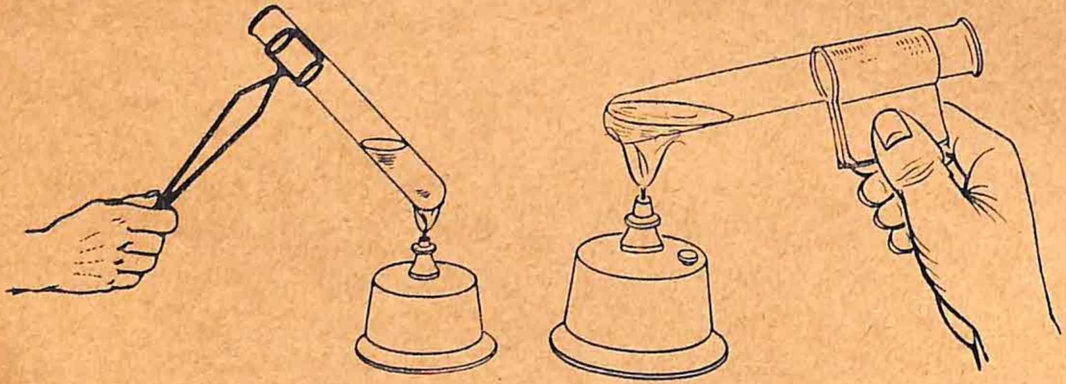
Remember that :

(a) A burning lamp should not be carried from one table to another.

(b) The lamp should be extinguished only by putting the cap and not by blowing.

B. Methods of heating

1. The upper part of the flame of a spirit lamp is the hottest zone. Any object to be heated should be held in this part of the flame.



a b

FIG. 12. Heating of a substance in a glass tube

a. A test-tube in a holder b. A test-tube in a paper strip

2. A naked flame can be used to heat a glass apparatus containing a substance to be heated. To heat a test-tube, it is better to employ a test-tube holder which can also be prepared from a strip of paper folded several times. (Fig. 12).

3. When you heat a substance in a test-tube, the entire substance should he heated in the beginning by warming the tube which may then be heated strongly without removing it from the flame.

Remember the following instructions

(a) When a liquid is being heated in a test-tube, see that the mouth of the test-tube is not directed towards you or your neighbours since there is a possibility of the liquid spurting out and causing burns.

(b) Do not heat a test-tube at the place where the level of the liquid touches it.

(c) The wick of the spirit lamp should not be touched by a heated test-tube as it is likely to crack.

(d) A large amount of a liquid should never be heated in a test-tube. The volume of the liquid should be one-third of the total capacity of the test-tube.

(e) Put out the spirit lamp immediately after use.

(f) Hot objects should not be left on the table. A test-tube containing a hot liquid should be kept in a stand provided for the purpose (Fig. 13) while a test-

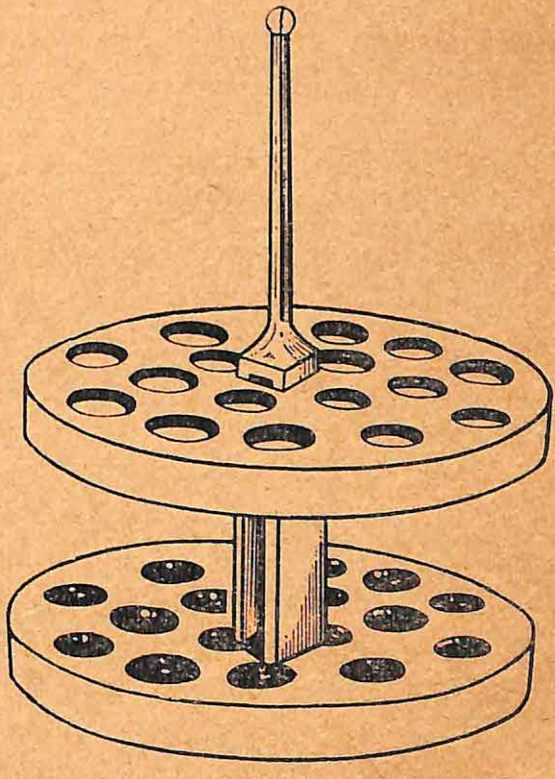


FIG. 13. A wooden stand for test-tubes

tube containing a hot solid may be placed on an asbestos sheet.

EXPERIMENT

Following the above instructions heat pure water in a test-tube to the boiling point. Draw a neat diagram to illustrate your experiment.

C. Use of metal stands in the laboratory

1. Observe how a laboratory stand is assembled by taking out the various parts and re-assemble them. Draw a figure and name the different parts.

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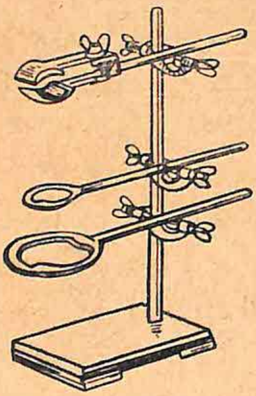

FIG. 14. A laboratory stand

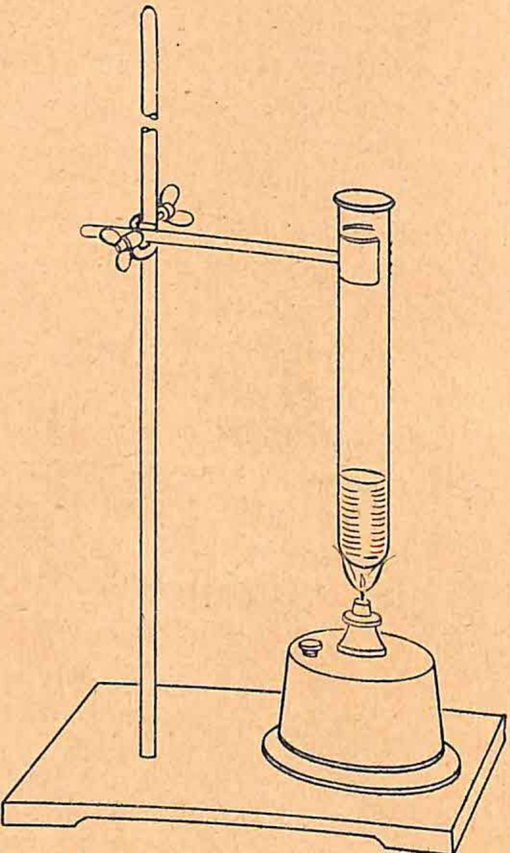

FIG. 15. Heating of a substance in a test-tube fixed on a stand

Exercise II : Fix a test-tube containing a small quantity of sugar on the stand by a clamp and hear it, observing the rules of heating.

Before starting the experiment, observe Fig. 15 carefully. What part of the test-tube should be fixed on the stand ? See that the test-tube does not break when the screw of the clamp is tightened. In what part of the flame is the bottom of the test-tube ? Note carefully the changes that the sugar undergoes on heating.

D. *Handling of glass apparatus*

Remember the following instructions regarding the use of the glass apparatus :

1. Usually the glass apparatus that are used in experiments in chemistry have thin walls and hence should be handled with care. These should not be kept on dirty table, especially when there is sand lying on the table, because even a small particle of sand may leave a scratch on the wall of the vessel which may crack on heating.
2. Do not place a hot apparatus on a cold surface. They may be kept on an asbestos pad or an asbestos gauze.
3. Glass apparatus should be washed with hot water and soap or soda. The inner surface may be cleaned by means of a soft brush.

   After washing the apparatus it should be rinsed with pure water. If a surface is cleaned properly water will trickle down and will not form droplets.

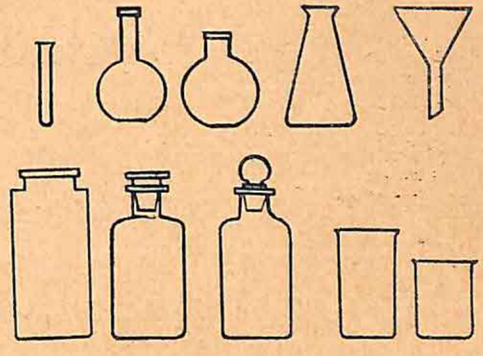

FIG. 16. Glass apparatus usually employed in a laboratory

From left to right

Test tube, Flasks, Conical beaker, Funnel, Bottles and Jar, Beaker.

4. Thick walled vessels are used for storing solutions and dry substances and for other purposes. These vessels should never be heated, nor should hot liquids be poured into them.
5. Measuring apparatus should be used for the measurement

of definite volumes of liquids. This apparatus should never be heated.

E. Other laboratory equipments

As you will be using other laboratory equipments, it is necessary to get acquainted with them. Some of these are shown in the figure below :

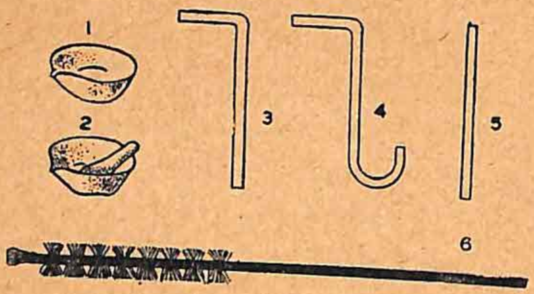

FIG. 17.

1. Procelain dish 2. Pestle and mortar
3. and 4. Glass tubes 5. Glass rod
6. Brush

F. Assembling a simple apparatus for the preparation of gases

See Fig. 18. On the left side are shown certain pieces of apparatus which may be assembled as shown on the right. Learn the names of each of them and also how they are assembled and mounted on stand.

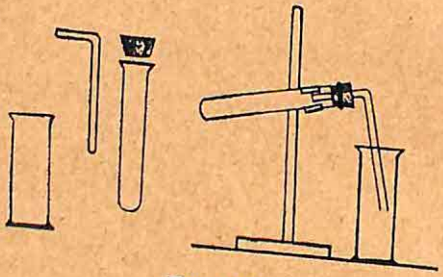

FIG. 18.

Instructions for assembling

(a) Hold the bent tube at its shorter end and introduce this end into the cork by a rotatory movement. A drop of water may be used to moisten the tube.

(b) To insert a glass tube into a rubber tube, the latter is held in the right hand and the former in the left. The rubber tube is then introduced with rotatory motion. Here also a drop of water may be used as a lubricant.

(c) Check up the apparatus and ascertain whether it is air-tight or not. For this purpose close the mouth of the delivery tube with your finger and dip the apparatus in a trough of water in such a way that the level of water stands above the cork. Warm the tube slightly. Gurgling of gas bubbles around the cork shows that the apparatus is not air-tight.

How do you explain this ? Why should you check whether the apparatus is air-tight or not ?

4. Pure Substances and Mixture

If one looks carefully at a piece of natural granite through a lens, it will be found that it is made up of a number of different substances, for example, colourless and coloured grains of quartz, shining scales of mica and white or pink pieces of felspar may be seen.

These three substances differ from one another in colour and some other properties. Quartz is so hard, that even scratching with a steel needle does not leave any mark on it, whereas mica and felspar are relatively soft. From what has been described above, it follows that granite is not a *homogenous* substance, but comprises a mixture of substances having different properties.

Mixture of different substances may be formed artificially also. For example, if we grind chalk and common salt together, using a mortar and pestle, we will get a fine powder in which the grains of salt and chalk will be indistinguishable to the naked eye. We can, however, show the presence of these two substances in the mixture as follows :

Take a small quantity of the mixture, add a little water, and stir well with a rod. Chalk, which remains insoluble in water may be separated from the dissolved salt, by pouring the solution into a vessel covered by a cloth, when the chalk is collected on the cloth. On evaporating the solution in the vessel we will obtain the salt.

In the above mixture, the two substances, salt and chalk, retained their respective properties. The molecules of chalk are identical but differ from those of salt.

Those substances that are made up of identical molecules are called **pure substances.**

Only those substances that are pure, have definite properties. They have definite melting and boiling points and have definite specific gravity. Pure alcohol, for instance, has a boiling point of 78°C and a specific gravity of 0.78 at 15°C.

Pure water boils at 100°C at normal atmospheric pressure, but if you add a little salt to water, the resulting solution will have a boiling point higher than that of pure water.

Natural substances are generally impure. They are usually mixtures of two or more substances. Natural water, for instance, contains dissolved impurities which are left behind on evaporation. It may also have suspended impurities which may give it a turbid appearance. The air that we breathe is also a mixture of different gases like oxygen, nitrogen, carbon dioxide, etc.

Sometimes difficulty arises in distinguishing a pure substance and a mixture, since outwardly a substance may appear to be homogeneous, but in fact it may be heterogeneous. Thus, for instance, one may feel that milk is a homogeneous substance, but on examining it under a microscope one could observe tiny droplets of fat floating in the liquid (Fig. 19). If milk is churned for sometime, cream can be seen floating on the surface. This cream consists of drops of fat.

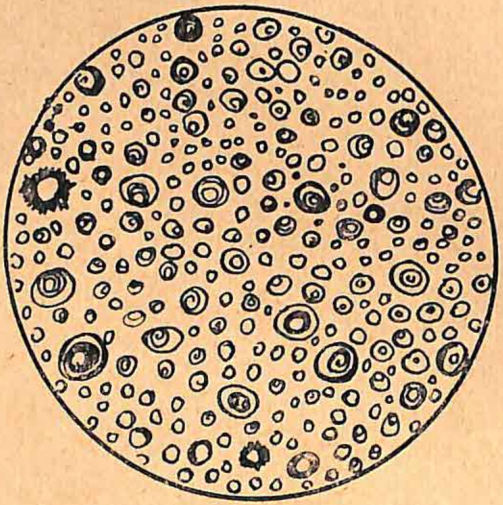

FIG. 19. A drop of milk under a microscope

We can determine the purity of a substance if we know exactly the physical properties like melting point or boiling point or specific gravity etc. of the pure substance. For example, we know that pure water has a boiling point of 100°C at atmospheric pressure (760 mm. of mercury).

If, then, we determine the boiling point of a given sample of water at atmospheric pressure, which is 100°C, the sample is pure. If on the contrary it is above 100°C the sample is impure.

Properties, like boiling point, melting point, specific gravity, of many pure substances have been experimentally determined and tabulated. These tables may be referred to by anyone who wishes to determine the purity of a substance.

QUESTIONS

1. What is a mixture ? Give examples.
2. How can you say whether a substance is pure or not ?
3. The properties of a mixture are different from those of pure substances—Why ?

5. Purification of Substances

Since impurities bring about a change in the properties of a substance, it is necessary to remove these impurities before using the substance. This process of removal of impurities from a substance is known as purification. The analysis of a mixture is based upon the difference in properties of its constituent (component) substances.

Purification of substances is done in technological and chemical laboratories by different methods. At present we shall discuss three of them, *viz.*, *decantation*, *filtration* and *evaporation*.

DECANTATION

Take a long glass jar or cylinder containing water and put some dry powdered earth (soil) in it and stir well by means of a glass rod or wooden stick and then let it settle down (see Fig. 20). What do you observe ? Which of the particles—larger or smaller—settle down first ? Why ?

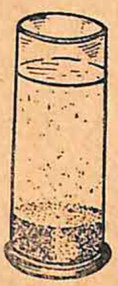

FIG. 20. Settling for decantation

Fill a test-tube to a third of its volume with water and then add a few drops of any vegetable oil (mustard oil etc.). Close the test-tube with a stopper, shake for some time and let it settle down. What do you see ? What properties of substances are utilized for distinguishing between the components of the mixture ?

Decantation is the process generally employed to separate solid mechanical impurities from liquids. The turbid liquid is left undisturbed in the vessel. First the larger particles settle down at the bottom and then the smaller ones. Purification of drinking water is done by leaving natural water undisturbed for a long time in huge reservoirs when the minute particles of earthpresent in water settle down at the bottom.

Two immiscible liquids can be separated by decantation. The lighter one floats on the heavier one and the two liquids separate into distinct layers which can be separated easily (Fig. 21). In laboratories, a separating funnel is used for this purpose.

Thus in the example of oil and water mentioned earlier, oil can be separated from water by pouring the mixture into a seperating funnel, allowing it to remain undisturbed for a while and when the two liquids separate into distinct layers, the lower layer is drawn out by opening the stopcock of the funnel (Fig. 22).

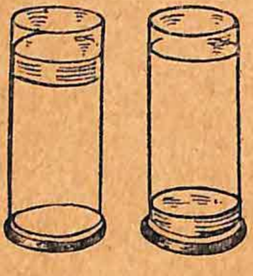

FIG. 21. A lighter immiscible liquid floats while a heavier one sinks

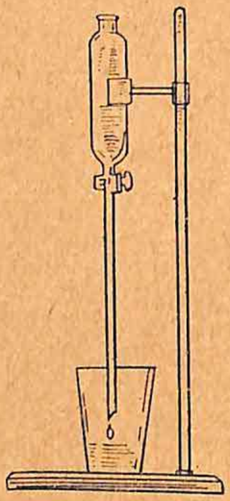

FIG. 22. Separating funnel

This method is employed for separating water from petrol. As water is heavier than petrol, it will settle down at the bottom, if petrol is left still in a cistern or a petrol separating column (Fig. 23). The petrol is then allowed to flow out, free from water.

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The examples given above show that the constituent substances of a mixture can be separated by decantation if they are of different densities. But it is not always possible to separate minute particles of solid substances from the liquids by decantation. For instance, very minute particles of mud present in water do not settle down, and the water remains turbid even after letting it stand for a long period. In such cases purification is effected by filtration. Filter paper is employed in laboratories for this purpose. Very minute pores in the paper, invisible to the naked eye, allow the liquid to pass through them, retaining the solid particles.

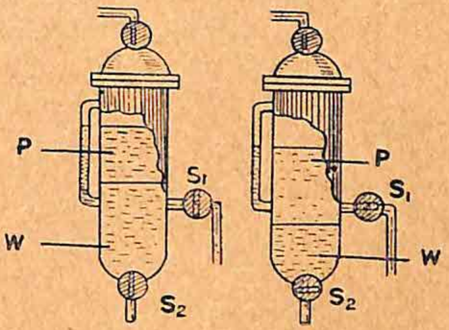

FIG. 23. Petrol separating funnel
P=Petrol
W=Water
S_1=Outlet for petrol
S_2=Outlet for water

FILTRATION

EXPERIMENTS

For the study of purification of substances by filtration, conduct the following experiments :

1. From a piece of filter paper, cut out a filter that suits the dimension of the funnel taken, so that on inserting the filter into the funnel, the top edge of the filter remains half a centimentre below the brim of the funnel. Fold the filter twice, as shown in Fig. 24, so that it forms a cone with three folds on one side and a single fold on the other.

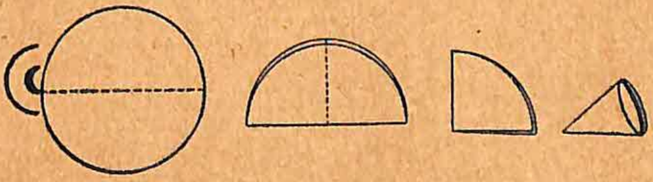

FIG. 24. Folding a filter paper

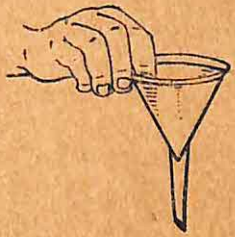

FIG. 25.

Put the filter paper into the funnel (Fig. 25), moisten it with a few drops of pure water, and place the funnel along with the filter

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paper in the ring of a stand or on the neck of a flask, as shown in Fig. 26.

Pour the liquid to be purified carefully into the funnel with the help of a glass rod, taking care that the level of the liquid in the funnel is not above the top edge of the filter paper. Compare the liquid that is poured into the filter paper with the liquid that has passed through it. Which is more transparent ?

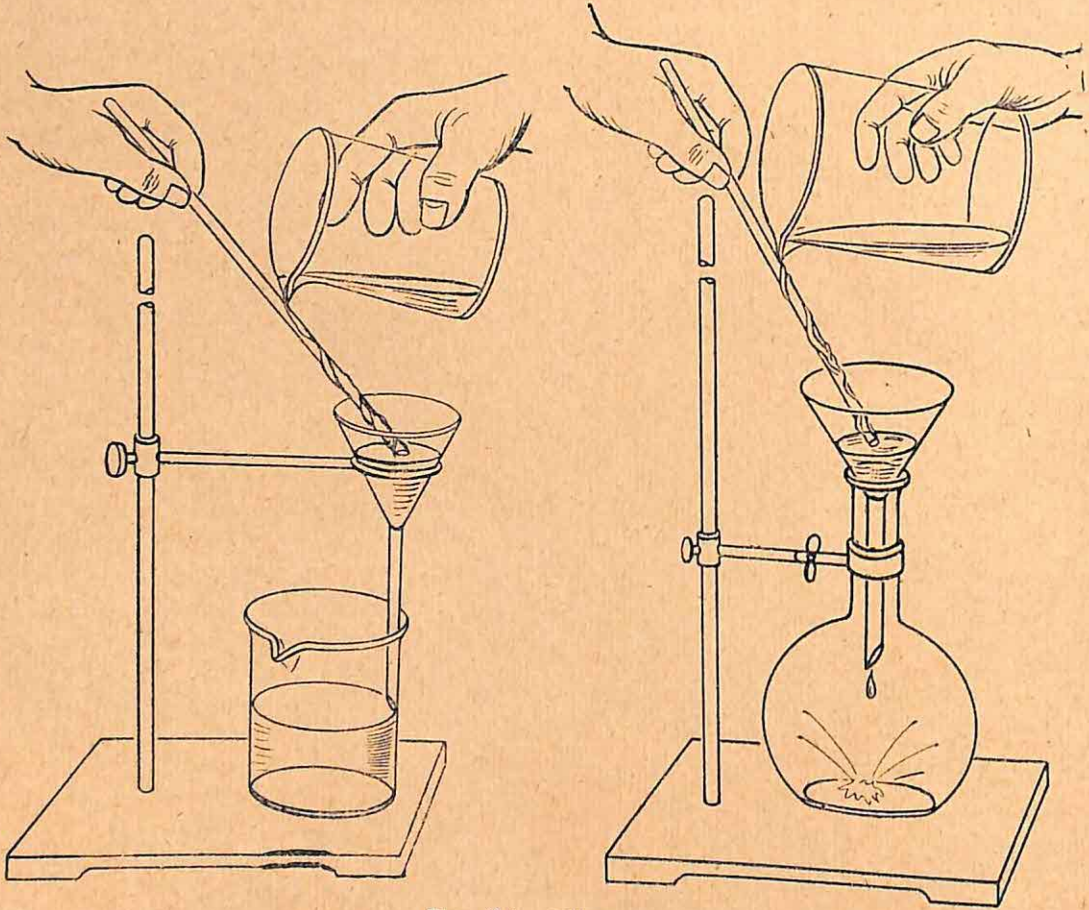


FIG. 26. Filtration

The liquid becomes more transparent after filtration since the insoluble solid impurities in water are retained by the filter paper.

Sometimes a cloth may be used in place of a filter paper. Only the separation of insoluble solids from liquids is possible in this case.

Another method of filtration that is sometimes employed in purifying town water supplies, is passing the water through a thick layer of sand. Separation of soluble impurities from liquids, *e.g.*, dissolved common salt in water, cannot however be effected by this method of filtration. This can be effected by distillation.

EVAPORATION

If it is required to obtain only the solid then it can be achieved by evaporation of the solution (Fig. 27). Thus during evaporation of a salt solution the salt remains in the basin after the evaporation of water. This method is utilized in the preparation of common salt from sea water, which is led into open salt pans, and allowed to evaporate. On evaporation of water the salt left in the pans is collected.

Apart from these methods of purification there are a number of other methods with which you will be acquainted at a later stage.

Purification of substances have a very important role to play in our daily life, since we cannot use impure substances in many cases. For instance, if copper contains impurities it will not be a good conductor of electricity and cannot be used for making electric wires. Certain metals used in radio and television demand a high degree of purity. All medicines should be thoroughly purified, lest the impurities should prove harmful. Similarly, pure substances are also required for laboratory work.

QUESTIONS

1. Why should substances be purified ?
2. What methods of purification are known to you ? Give some of their applications.
3. Some pieces of cork and paper fell in a jar containing pure common salt. Suggest the method by which you can purify the salt.
4. Suggest a suitable method for separating the following mixtures into their components :
    (i) Sand and common salt
    (ii) Sand and charcoal
    (iii) Common salt and powdered chalk
    (iv) Water and kerosene oil

LABORATORY WORK

Purification of Common Salt

Apparatus and regent required. Retort stand with ring, filter paper, funnel, balance, glass rod, evaporating dish, common salt, test-tube, conical flask, reagent bottle.

Procedure. Take about 5 of grammes of salt to be purified, in a beaker, and add about 20 ml. of water to it (one test-tube full). Mix the salt and water with the glass rod until it forms a uniform solution. Is it transparent or turbid ? Filter it, if turbid.

2. Assemble the apparatus for filtration and filter the solution following the rules of filtration.

3. Pour half of the filtrate into an evaporating dish, place the dish on the ring of the stand and evaporate the liquid by heating the dish by a spirit lamp, taking care that the flame just touches the bottom of the dish (Fig. 27). This is done to prevent spurting of liquid during evaporation. Continue the process till the dish becomes dry. Then only salt remains in the dish.

4. Collect the salt thus obtained on a sheet of paper and observe it. Can you notice any difference between this salt and the impure one you started with ?

5. Put the purified salt in a reagent bottle and label it as "Purified Common Salt."

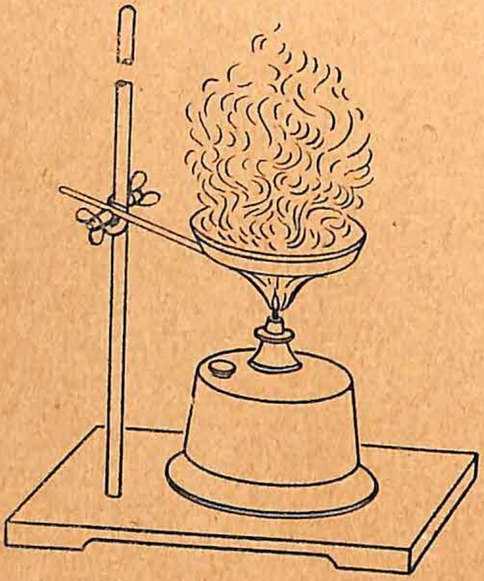


FIG. 27. Evaporation

6. Pour the filtrate remaining in the conical flask into another evaporating dish and keep it for evaporation in open air and in a warm place, protecting it from dust.

7. Clean the place of your work and prepare a record of the work done, following the instructions of your teacher.

6. Physical and Chemical Phenomena

Have you observed what happens when water is kept in an open vessel or when a plant or tree lies uprooted or when an article made of iron is allowed to remain in a damp place ? Do they change or remain unchanged ? If you observe carefully, you will notice that water kept in an open vessel evaporates, the fallen plant or tree decays and the iron articles laying in the damp place get a coating of rust on it. In all these cases the substances undergo changes.

In nature, all substances undergo various changes. Sometimes many of these changes are effected with the active participation of man. Thus changes occur when wood and coal are burnt in furnaces, or stone is broken into pieces by machines, or mixed clay and sand are baked into bricks or ores melted to produce metals, or when water is boiled and food cooked. You can yourself find out from daily life many more examples of changes that substances undergo.

All changes taking place in the world around us are called phenomena. If we know the properties of various substances we can subject them to changes. Let us see how this can be done with the help of some experiments.

EXPERIMENTS

1. Place a beaker containing about 10 ml. of water on a wire gauze covered with asbestos in the centre and heat it by means of a spirit lamp or a gas burner. The wire gauze with asbestos ensures uniform heating and prevents the cracking of the glass.

When the water boils, cover the beaker with another beaker

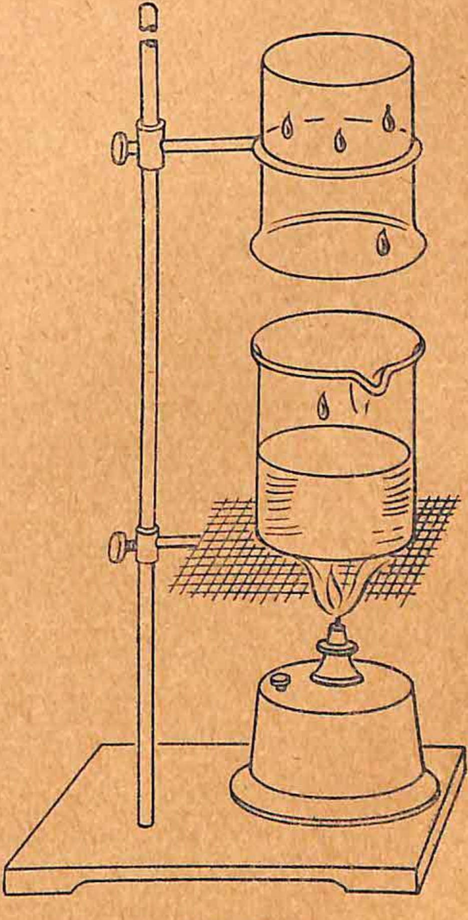


FIG. 28.

(Fig. 28). What do you observe on the walls of the upper beaker ?

2. Hold a small piece of copper plate with a pair of tongs or clamp it to a stand. Heat it over the flame of a spirit lamp till it becomes red-hot. (Fig. 29). Notice the changes that take place. Allow the plate to cool. Does it regain its original appearance on cooling ? Scrap the black coating of the plate by a knife, and collect it on a piece of paper. What do you see under the surface of the black coating ? Repeat the experiment. Do you find any resemblance between the black powder you have obtained and metallic copper ?

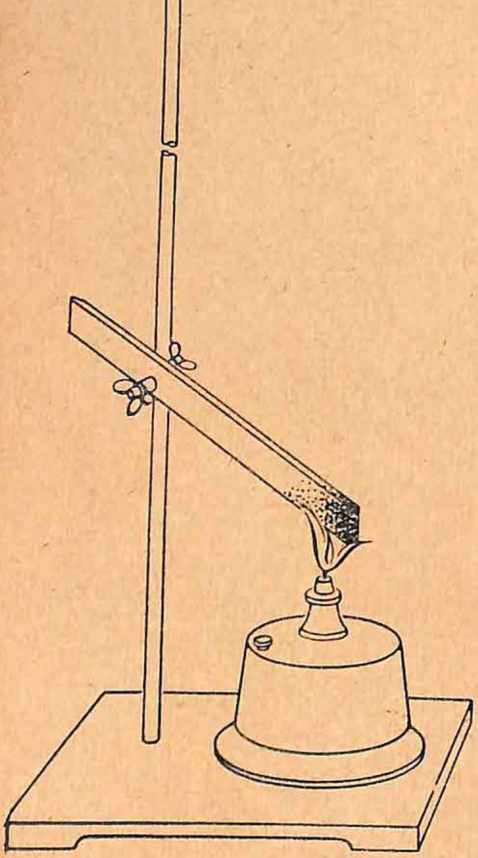


FIG. 29. Heating copper plate

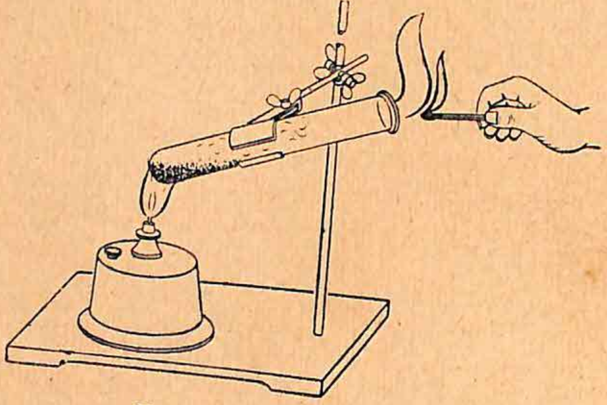


FIG. 30. Heating starch or sand

3. Heat some starch in a test-tube and observe the changes it undergoes. Similarly, observe the change, if any, when some clean sand is heated in another test-tube (Fig. 30).

Answer the following questions :

1. In which experiments the properties of substances undergo changes ?
2. In which of these experiments new substances having properties different from those of the original ones, were obtained?

You could see from these and other experiments that the changes that substances undergo can be divided into two types. The first type is the one in which only the physical condition of a substance changes and no new substances are produced. For example, water on heating turns into vapour, but on cooling liquid water is obtained again. Similarly, on freezing water you get ice and by melting the same ice you get the water back. On cooling a piece of red-hot iron it regains its original appearance. Again, a piece of glass tube softens on heating. It could then be stretched out or bent when held in a flame. In this case also, only the form of the object changes, and no new substance is formed.

The changes in substances where only the form or the physical condition undergoes a change without formation of any new substances are called **physical phenomena**.

The second type is the one in which a new substance having properties different form those of original substance is formed.

For instance, a number of new substances are produced when starch is heated.

A ribbon of magnesium held in a flame burns with dazzling brilliance, forming a white powder. This powder, known as magnesium oxide, is as different from magnesium as the oxide of copper from copper.

The changes in substances where one type of substances gives rise to new ones, are called **chemical phenomena.**

Chemical phenomena take place in the process of burning, rusting of iron, in the production of metals from ores and in several other changes that substances undergo.

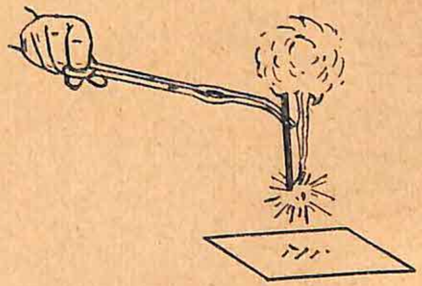


FIG. 30(a). Burning of magnesium

Chemical phenomena may also be called **chemical reactions.**

The basic task of chemistry is the study of chemical reactions between various substances.

QUESTIONS

1. Give examples of the changes that substances undergo in nature.
2. What are the physical and chemical phenomena? Give examples from your everyday life. What is the difference between the two?
3. The filament of an electric lamp shines brightly when the electric current passes through it. Is this phenomenon physical or chemical? Why?
4. Classify the following phenomena under the two types (physical and chemical):
   (i) Rusting of iron
   (ii) Conversion of a piece of glass into white powder by powdering it
   (iii) Formation of clouds
   (iv) Burning of candle
   Give reasons for your answer.
5. How can you say whether a chemical reaction takes place when milk turns sour?
6. Explain whether a chemical reaction takes place when curd kept for a while in summer develops an unpleasant taste and smell?
7. When a pressure stove works, vaporization of kerosene takes place and it burns. Which of these two processes is chemical?

7. Indications and Conditions of Chemical Reactions

New substances are always formed during a chemical reaction. These can be detected by their appearance, colour, odour and other properties. Thus it can be seen that external indications can show the existence of a reaction.

PRACTICAL WORK

1. Take a test-tube fitted with a cork and a delivery tube. Remove the cork and pour a few ml. of hydrochloric acid into the test-tube and then put a few pieces of marble chips. Replace the cork carrying the delivery tube. What do you observe in the test-tube? Dip the end of the delivery tube in lime water contained in another test-tube. Observe what happens to the lime water. Feel the bottom of the test-tube containing the acid and marble chips. What do you feel?

2. Introduce a burning splinter into the test-tube containing lime water, without allowing it to come in contact with the lime water (Fig. 31). What happens?

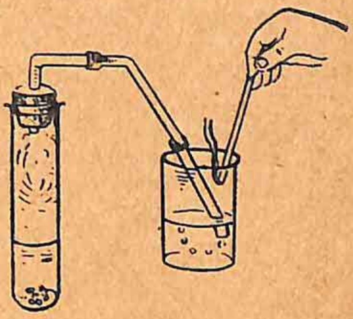


FIG. 31. Reaction of marble with hydrochloric acid

On the basis of experiments performed, what are the indications of a chemical reaction?

Liberation of *heat* is one of the important indications of a chemical reaction. In the case of some reactions a small quantity of heat is liberated while in some others a large quantity of heat is generated. A lot of heat is liberated during the burning of fuels. This heat is used in the cooking of food, the heating of premises and also for setting machines into motion.

Production of *light* is also an indication of several chemical reactions. For example, magnesium burns with a brilliant dazzling light.

Some reactions are characterized by the production of *electric current*. For instance, such reactions take place in the dry cells of flash lights, transistors, etc.

In chemical reactions substances interact, *i.e.*, they act with each other. Hence we call a chemical reaction a chemical interaction also.

Certain conditions are required to be fulfilled if chemical reactions are to start and proceed.

One of them is *mutual contact* of the substances. For example, marble reacts with hydrochloric acid only when the two substances are brought into contact with each other.

Many reactions would start only, when *heat* is supplied, whereas others would take place in the presence of *light*. You have learnt that photosynthesis in leaves takes place in the presence of sunlight.

Conditions under which chemical reactions take place are quite varied. These conditions are often created in nature. Thus, for instance, rocks are changed by the action of water and air. When lightning strikes, combustible substances catch fire.

One of the most important tasks of chemistry is to study the conditions necessary for starting a reaction and its continuation. The knowledge of these conditions would enable us to control chemical reactions and direct their course. Thus, by knowing the conditions under which substances burn, we could arrange things in such a manner as to obtain more heat. Conversely, the conditions could be so regulated as to retard and to completely stop burning. Similarly, if we know the conditions under which rusting takes place we could take steps to protect iron goods from rusting and destruction.

From time immemorial, when chemistry was not developed as it is today, man saw many chemical phenomena in nature and tried to make practical use of some of them, without knowing properly the properties of substances and the conditions under which chemical actions take place.

Hence chemical phenomena was considered by them to be something secret and puzzling and their reproduction was considered to be a secret art. Some of the external indications of chemical phenomena such as ignition of substances, formation of visible subtances from invisible gases, creation of coloured substances from colourless ones, etc. were considered as miracles that could be brought about only by superhuman powers which were beyond ordinary human will and wishes. These superstitions continued for a long time till the development of chemistry showed that there was nothing mysterious or miraculous in the chemical phenomena. These could not only be explained, but also controlled or directed according to our wishes. Chemistry today, along with other branches of science like mathematics, physics, biology, geology and astronomy etc., plays great role in unravelling the secrets of nature.

From what you have learnt so far, you may see that chemistry is that branch of science that deals with substances and their properties, the changes that they undergo and the methods by which these changes could be brought about and regulated.

QUESTIONS

1. Explain with examples what you understand by external indications of chemical reactions.
2. What are the conditions necessary for chemical reactions ? Give examples. Why should these conditions be known ?

CHAPTER II

Structure and Composition of Substances

8. Decomposition Reaction

It can be shown with the help of experiments and observations, that new substances are formed as a result of chemical reactions. We can see what happens when powdered basic carbonate of copper is heated. It is also found in nature in the form of a green mineral called *malachite*.

EXPERIMENT

Fit up the apparatus as shown in Fig. 32. Fill up a quarter of the test-tube with basic carbonate of copper. Dip the end of the delivery tube in a beaker of lime water. Heat the test-tube for a few minutes and observe the changes that occur during heating.

Why does the lime water in the beaker turn turbid (milky)? What new substance do you see formed on the cold walls of the test-tube? Is any other substance formed as a result of heating basic carbonate of copper?

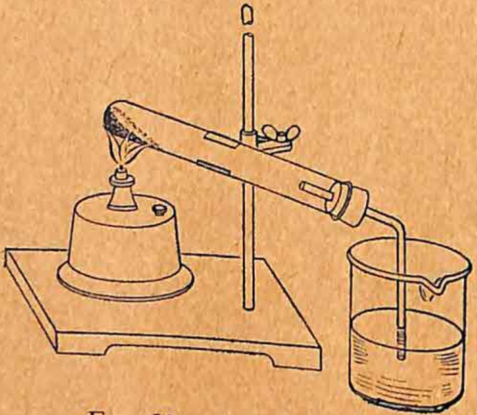


FIG. 32. Decomposition

The experiment shows that on heating the basic carbonate of copper three new substances are obtained, *viz.*, copper oxide, water and carbon dioxide. This may be expressed as follows :

$$\begin{array}{c}\text{Basic carbonate}\\ \text{of copper}\end{array} \xrightarrow{\text{on heating}} \begin{array}{c}\text{Copper oxide}+\text{water}+\\ \text{carbon dioxide}\end{array}$$

None of the products, copper oxide, water or carbon dioxide, was present as such in basic carbonate of copper. These three substances were formed as a result of a chemical reaction during which the basic carbonate of copper molecules decomposed to form molecules of three new substances, *viz.*, copper oxide, water and carbon dioxide.

Let us take another substance, yellow mercuric oxide, to study such a reaction.

A small quantity of this substance is taken in a test-tube fitted with a delivery tube, the end of which is dipped in water. The test-tube is fixed on a stand and then heated. After a while bright drops of mercury can be seen collected on the cooler parts of the test-tube and gas bubbles can be seen escaping through the delivery tube. After allowing a few bubbles to escape, the gas is collected in a test-tube by the downward displacement of water. The gas thus collected is tested by means of a glowing splinter, which bursts into flame, thereby showing that the issuing gas is oxygen. From this experiment it can be seen that on heating mercuric oxide, two substances, namely, mercury and oxygen, are obtained.

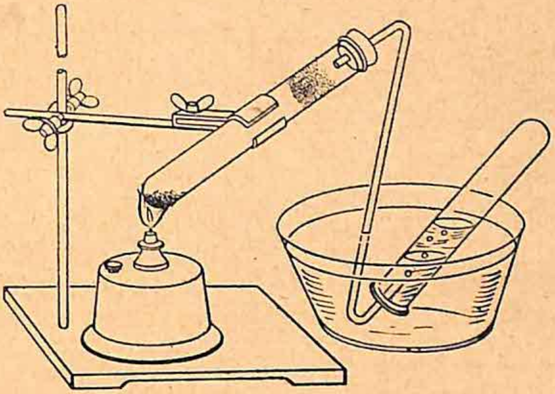


FIG. 33. Decomposition of mercuric oxide

$$\text{Mercuric oxide} \xrightarrow{\text{heat}} \text{Mercury}+\text{Oxygen}$$

Mercuric oxide is a pure substance, made up of molecules of only one type. It contains neither bright drops of mercury nor oxygen gas. These two substances were formed during the reaction that took place on heating mercuric oxide. Molecules of mercuric oxide were decomposed to form the molecules of oxygen and mercury.

Now let us see what happens when an electric current is passed through water containing a little acid or common salt. For this we shall use one of the two apparatuses shown in Fig. 34. On passing an electric current, bubbles of gas are collected in the two electrode compartments. We find that the volume of gas collected in one of them is twice the volume of the gas collected in the other. These gases can be easily recognized. If we introduce a glowing splinter into the gas which is of smaller volume, the splinter bursts into flame showing that the gas is oxygen. But when we bring the splinter near the other gas, the gas itself burns. This gas is hydrogen.

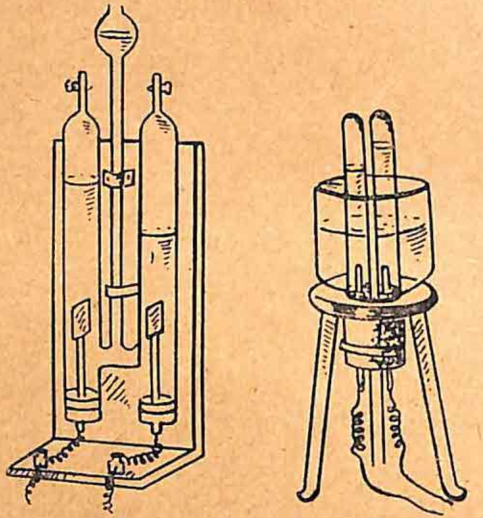


FIG. 34. Decomposition of water by electricity

Thus we find that on passing an electric current through water, two new substances, namely, oxygen and hydrogen, are obtained.

$$\text{Water} \xrightarrow{\text{electric current}} \text{Oxygen} + \text{Hydrogen}$$

Chemical reactions in which two or more new substances are obtained from one substance, are called **reactions of decomposition**.

QUESTIONS

1. On heating red-lead (minium), oxygen and a yellow powder called lead oxide were obtained. Represent this reaction schematically.
2. What is a reaction of decomposition ? Give examples in which one substance gives rise to two new substances.
3. To which type of reactions do the following belong ?
   - (i) On heating silver oxide, silver and oxygen are formed.

(ii) On heating baking soda, water, carbon dioxide and washing soda are formed.

9. Reaction of Combination

In the reactions of decomposition we have seen how one substance gives rise to two or more new substances. Now let us see if two or more different substances can combine together to form a new substance. For this purpose the following experiment may be conducted.

FIG. 35. Powdered Sulphur and iron in water

EXPERIMENT

Examine the iron and sulphur powders given to you. How do they differ in their appearance ? Drop a small quantity of each, separately, into water (Fig. 35). What do you observe ? Take a magnet near the powders, one after the other. What do you observe ? Now prepare a mixture of the two substances by grinding them together on a paper or in a mortar. Divide this mixture into two portions. See how this mixture reacts to a magnet brought near it. Which of the two substances is attracted by the magnet (Fig. 36) ? Put some mixture into a vessel containing water and shake well. What do you observe ? What inferences can you draw ?

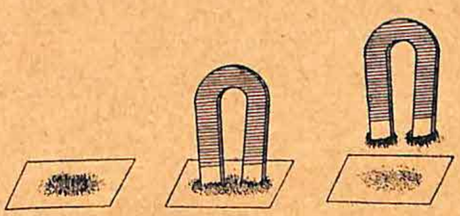


FIG. 36. Separating a mixture of iron and sulphur by magnet

The dark brown iron powder sinks in water and is attracted by a magnet. The yellow sulphur powder is neither attracted by a magnet nor does it sink. It is also not moistened by water. Only iron is attracted by the magnet when it is brought near the mixture of iron and sulphur. Again, only iron sinks to the bottom when the mixture of iron and sulphur is put into a vessel containing water, whereas sulphur floats on the surface. Thus we see that iron and sulphur in the mixture have the same qualities as in their individual existence and that no new substance is formed by mixing up these two substances. In other words, a chemical reaction does not take place in this process.

Now take a test-tube containing a mixture of definite quantities of iron (7 parts) and sulphur (4 parts) by weight and fix it on a stand. Heat the upper portion of the mixture. Remove the source of heat when you see the upper portion glowing. Observe what happens in the test-tube (Fig. 37). When the test-tube gets cooled, break it in a mortar with a pestle. After removing the glass pieces with the forceps, put a little powder into water. What do you observe? What inference can be drawn?

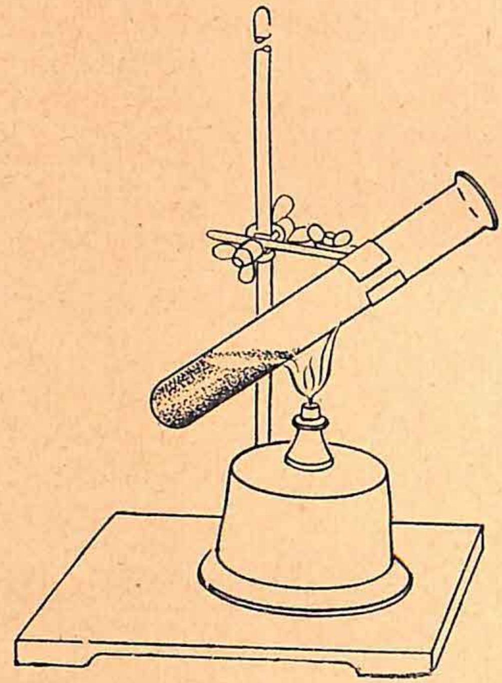


FIG. 37. Heating iron and sulphur

We will find that on heating the upper portion of the mixture of iron and sulphur in the test-tube, an intense heating of the contents takes place. This indicates that heating of the mixture at one place brings about a chemical reaction between sulphur and iron, accompanied by the evolution of a large quantity of heat. The product of the reaction differs from the initial substances (reactants). It has a different colour, sinks in water without getting separated into sulphur and iron.

Thus as a result of chemical action, the substances, sulphur and iron, have lost their original properties. A new substance, iron sulphide, having its own characteristic properties, is formed out of them. This may be represented as :

$$\text{Iron}+\text{Sulphur}\xrightarrow{\text{heat}}\text{Iron sulphide}$$

Now let us take one gm of zinc dust and 0.5 gm of sulphur and mix them together thoroughly on a piece of paper. The mixture is sprinkled on an asbestos sheet or on an iron plate and then a burning splinter is brought near the mixture. A flash is observed, indicating that a chemical reaction between the two substances has taken place.

As a result of this reaction, a new substance, zinc sulphide, is formed. It is a white powder.

$$\text{Zinc} + \text{Sulphur} \xrightarrow{\text{heat}} \text{Zinc sulphide}$$

In both the above experiments you have seen how a new substance is formed from two given substances.

> *Chemical reactions in which two or more substances combine together to form a new substance are known as* **reactions of combination**.

QUESTIONS

1. Aluminium reacts with sulphur to form aluminium sulphide. What type of reaction is this ?
2. On grinding iodine with mercury in a mortar, a yellowish green powder of mercurous iodide is formed. To what type this reaction belongs ?

10. Atoms

In the experiment showing the decomposition of mercuric oxide you observed that new substances, mercury and oxygen gas, were formed. Mercuric oxide being a pure substance, consists of only one type of molecules. Neither free mercury nor gaseous oxygen is present in it. It follows that these substances are formed as a result of the molecules of mercuric oxide.

Similarly, two substances, hydrogen and oxygen, were formed when water was decomposed by passing an electric current through it. But water also is composed of only one type of molecules and neither free hydrogen nor free oxygen is present in it as such. These are formed by the decomposition of water molecules.

$$\text{Water} \xrightarrow[\text{current}]{\text{electric}} \text{Hydrogen} + \text{Oxygen}$$

Thus we find that molecules of water and mercuric oxide are composed of particles even smaller than themselves. These particles do not decompose in a chemical reaction. For instance, it is not possible to decompose mercury or oxygen, hydrogen or sulphur to get new substances.

These minute and chemically indivisible particles which form molecules are known as **atoms**.

Molecules of oxygen, hydrogen and sulphur are composed of only atoms of oxygen, hydrogen and sulphur respectively, whereas mercuric oxide molecules are composed of atoms of mercury and oxygen, and molecules of water are composed of atoms of hydrogen and oxygen. Similarly, iron sulphide molecules contain atoms of sulphur and iron.

During the decomposition of mercuric oxide, its molecules break up into atoms of mercury and oxygen. This reaction may be represented as follows:

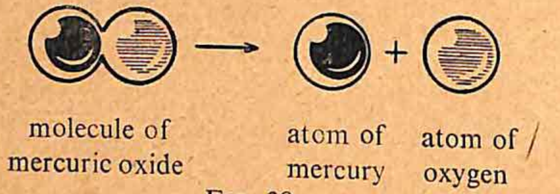


FIG. 38.

A pair of oxygen atoms combine to form a molecule of oxygen and these molecules comprise the gaseous oxygen.

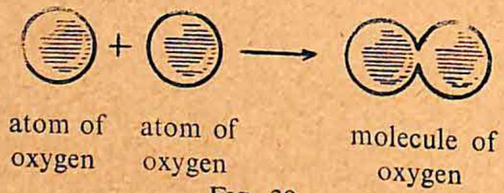


FIG. 39.

A molecule of water consists of two atoms of hydrogen and one atom of oxygen. On decomposition the molecule of water breaks up into these atoms:

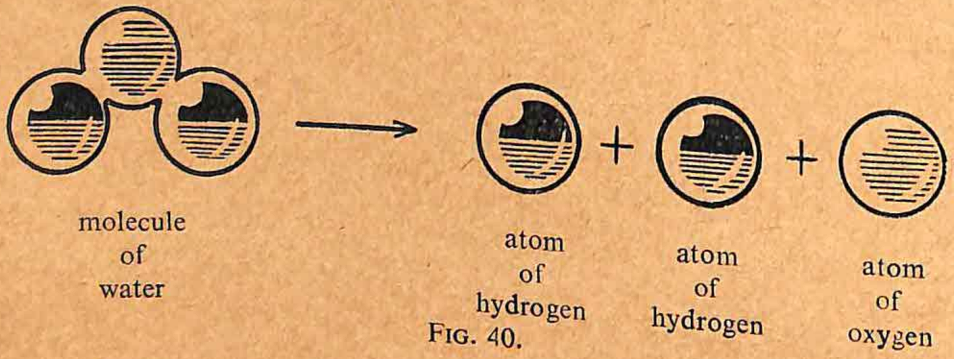


FIG. 40.

The decomposition of a large number of molecules of water takes place at the same time and hence a large number of atoms are formed. These atoms then combine together to form molecules as shown below.

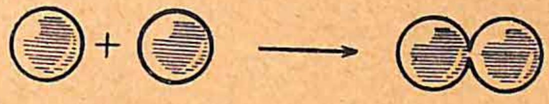


FIG. 41.

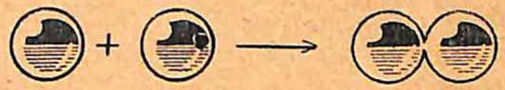


FIG. 42.

11. Atomic Weight

Atoms are very tiny particles and have extremely small weights. One of the heaviest of atoms, *viz*., the atom of uranium weighs only 0.000,000,000,000,000,000,000,396,67 grammes. Other atoms have even smaller weights. It is not convenient to use such small numbers in various calculations.

At the beginning of the 19th century, John Dalton, an English scientist, suggested that the weight of different atoms can be compared with the weight of an atom of hydrogen. Hydrogen is the lightest element known. Since its atom is the lightest, its weight was taken as the unit for comparison. Thus an atom of oxygen was found to be 15.88 times heavier than an atom of hydrogen. The weights of other atoms also came out in fractions. For practical convenience, it was decided to take the weight of an atom of oxygen as 16 and the unit of measurement of the atomic weight was accepted as one-sixteenth part of the weight of an oxygen atom. It was named as the oxygen unit (OU).

Weight of atoms expressed in oxygen units is called **atomic weight**.

Thus the atomic weight of an atom shows as to how many times the given atom is heavier than 1/16th part of the weight of an oxygen atom.

The atomic weight of mercury is 200.61 oxygen units. This shows that each atom of mercury is 200.61 times heavier than the weight of 1/16th part of an atom of oxygen. An atom of hydrogen is 1.008 times heavier than the weight of 1/16th part of an atom of oxygen and hence its atomic weight is 1.008 oxygen units. Similarly, the atomic weights of sulphur, copper, carbon and magnesium are 32.006, 63.54, 12.011 and 24.32 oxygen units respectively.

Though the atomic weights of all the elements have been experimentally determined with great precision, in practice, the atomic weights are generally used in round figures. For example,

Sulphur	32
Magnesium	24
Copper	63.5
Hydrogen	1
Oxygen	16

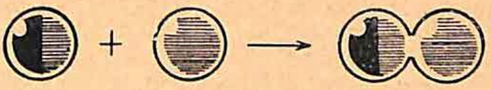
QESTIONS AND EXERCISES

1. What are atoms?
2. Of what atoms are the molecules of the following substances composed?
   (a) Mercuric oxide, (b) Water, (c) Iron sulphide
3. What is the oxygen unit? What is meant by the term atomic weight?
4. (i) How many times is an atom of magnesium (a) heavier than an atom of oxygen, (b) lighter than an atom of sulphur?
5. How many times is an atom of magnesium heavier than (a) an atom of carbon, (b) an atom of hydrogen?
   (The atomic weight may be taken in round figures).
6. Zinc oxide molecule consists of one atom of zinc and one atom of oxygen. Sixty-five parts by weight of zinc and 16 parts by weight of oxygen combine together to form zinc oxide. What is the atomic weight of zinc? (Solve this problem orally).

7. In sulphur dioxide one part by weight of sulphur and one part by weight of oxygen are present. If the molecule of sulphur dioxide consists of one atom of sulphur and two atoms of oxygen, what is the atomic weight of sulphur ?

12. Simple and Compound Substances

For the preparation of iron sulphide we had taken two separate substances, iron and sulphur (page 36). Iron and sulphur are composed of only the atoms of iron and sulphur respectively. Iron sulphide was obtained only when sulphur and iron combined together. The molecules of iron sulphide, therefore, do not consist of identical atoms but of different atoms, *i.e.*, atoms of iron and atoms of sulphur as represented below.



atom of iron + atom of sulphur = molecule of iron sulphide

FIG. 43.

Similarly, the molecules of mercuric oxide, water, basic carbonate of copper, etc., are also composed of different atoms. These substances can be decomposed to form new substances. The substances like sulphur, hydrogen, oxygen, mercury, etc., cannot be decomposed to form new substances because their molecules consist of atoms of only one type.

The substances whose molecules are composed of atoms of only one type are known as **simple substances.**

Examples of simple substances are sulphur, iron, mercury, copper, zinc, oxygen, hydrogen, etc.

Substances whose molecules consist of atoms of different types are called **compound substances**.

Examples of compound substances are water, iron sulphide, copper oxide, carbon dioxide, mercuric oxide, etc. These substances can be decomposed to form new substances, and can be obtained by the combination of two or more substances. For instance, iron and sulphur, on combining together, give iron sulphide. Iron sulphide is therefore a chemical compound of sulphur and iron. Similarly, mercuric oxide is a chemical compound of mercury and oxygen.

Simple substances are very few in comparison to the compounds. At present only about 300 simple substances are known, whereas the number of compounds is supposed to be over two million.

QUESTIONS AND EXERCISES

1. What are simple substances? Name some simple substances which you know.
2. Can we obtain simple substances by the combination of two or more substances?
3. What is a compound? Name some compounds consisting of two elements.
4. What is the minimum number of kinds of atoms required to form a molecule of a compound?
5. How can we prove that the following substances are compounds: mercuric oxide, water, basic carbonate of copper.

13. Atom-Molecular Study

Atom-molecular study means the study of the structure of substances composed of atoms and molecules. As far back as the 6th century B.C., the Indian philosopher Kanada regarded matter as being made of minute indivisible particles called *paramanu* (atom of today). He thought that these combined to form bigger particles called *dvayanuka* or *triyanuka* (present day molecules). The ancient Greek scholars of the 5th and 4th century B.C. also had thought of substances as being composed of extremely small indivisible particles. But their notions were different from those that are prevalent today, since they held that the atoms of all substances are identical in their properties.

In the middle of the 18th century, M.V. Lomonosov, a Russian scientist, felt that for a proper study of substances it was necessary to know how and of what they were made. According to him the properties of substances depended upon the type of the very minute particles of which their corpuscles were composed. (Corpuscles is the word Lomonosov used for molecules.) These corpuscles may be simple or complex, *i.e.*, they may be composed of identical or different smaller particles (atoms).

In the beginning of the 19th century, John Dalton, an English chemist, developed similar ideas. By the middle of the century, atom-molecular studies acquired a firm position. Their basic principles may be summarized as follows :

1. Substances are composed of extremely minute particles, *i.e.*, molecules, which have interstices between them. These are in constant motion.
2. All molecules of a given substance are identical, while those of different substances differ from one another in weight, chemical properties and dimensions.
3. Molecules are composed of atoms. Molecules of simple substances are identical while those of complex substances (compounds) are composed of different kinds of atoms.
4. Like molecules, atoms are also in constant motion.
5. Atoms of one type differ from those of another in weight, dimensions and chemical properties.
6. Atoms are neither created nor destroyed in chemical reactions.

A variety of chemical transformation of substances could be explained by atom-molecular studies. Thus in the decomposition reactions molecules of new substances are formed from atoms comprising the molecules of the initial compound substances.

It should be understood clearly that a chemical reaction does not involve merely a simple transference of atoms from one molecule to another and that a molecule is not merely a simple sum total of atoms. For example, in the molecules of iron sulphide we do not find the properties of free iron or free sulphur. Similarly, molecules of water differ in properties from the molecules of either free oxygen or free hydrogen. Hence water is a chemical compound (as it is not a mixture of these simple substances, *viz.*, oxygen and hydrogen).

During the first half of the 20th century a lot of new information regarding the structure of substances has been obtained. It is now known that although atoms cannot be decomposed by a chemical reaction, nevertheless, they are complex in structure, and are composed of even smaller particles than themselves. Some of these are electrons, protons and neutrons.

Today we can obtain one type of atom from another by means of complex physical devices and apparatus. These transformations are accompanied by the evolution of tremendous amount of energy—atomic energy—which is being used for many purposes. The atomic reactor station at Trombay, near Bombay, is one such centre in our country where energy is manufactured from atoms. The radio-isotopes prepared in this reactor are being used in medicine and agriculture.

QUESTIONS AND EXERCISES

1. State the fundamentals of atom-molecular study and give its signficance in chemistry.
2. Explain the following reactions on the basis of atom-molecular studies :
    (i) Decomposition of mercuric oxide.
    (ii) Decomposition of water.
    (iii) Combination of sulphur with iron.

14. Chemical Elements

We know that the properties of various substances differ from one another. Thus, the properties of sulphur are different from the properties of copper and the properties of oxygen differ from those of iron. The properties of substances depend upon the properties of molecules and atoms of which they are composed. Iron sulphide differs in properties from mercuric oxide and sugar from common salt, because the molecules of these substances are formed from different atoms.

Atoms of different substances differ in their chemical properties. Atoms of iron can combine with atoms of sulphur but not with those of zinc. Similarly, atoms of mercury can combine with atoms of oxygen but not with atoms of iron. Futhermore, atoms differ in the magnitude of their atomic weights; thus, for instance, sulphur atoms (atomic weight 32) are nearly half as heavy as the atoms of copper (atomic weight 63.5) but twice as heavy as the atoms of oxygen (atomic weight 16).

Water molecules contain oxygen atoms. These atoms are also present in the molecules of mercuric oxide and cupric oxide. They also combine to form the molecules of the simple substance oxygen which is present in air. Now these atoms of oygen which form the molecules of the simple substance and also are part of many complex substances (compounds) have all one thing in common and that is that they represent a type of atoms.

Similarly, atoms of sulphur belong to another type of atoms which can form the simple substance sulphur or remain in combination in substances such as iron sulphide. A third example is that of atoms of copper which are present in copper metal and its compounds like cupric oxide and basic carbonate of copper.

Atoms of one type are called **chemical elements**

Thus atoms of oxygen represent the chemical element oxygen, those of copper, sulphur and iron represent the chemical elements copper, sulphur and iron respectively.

If the two simple substances sulphur and iron are mixed together we get a mixture in which the properties of these two simple substances are retained. But it has been seen in earlier experiments, that in the case of iron sulphide (a complex substance or compound) we do not observe the properties either of the simple substances iron or sulphur.

Iron sulphide, therefore is not composed of a simple substance but consists of the elements sulphur and iron.

Again, in water both hydrogen and oxygen are not present as simple substances. The molecules of water consist of atoms of two elements, oxygen and hydrogen, which are chemically united with one another. On decomposition of water these elements, hydrogen and oxygen, are evolved in the free state and form the simple substances hydrogen and oxygen. Hence chemical elements are component parts of complex substances and they too form simple substances in their free state.

Molecules of complex substances consist of simple substances that conist of the atoms of one element. Thus atoms are the tiniest particles of a chemical element. 104 chemical elements are known till now. The 104th element was discovered only recently and was named Dubnium after the Russian Nuclear Research Institute at Dubna.

Chemical elements are divided into metallic and non-metallic elements on the basis of the properties of the simple substances they form.

The simple substances called metals are made up of metallic elements in their free state. Excepting mercury, *which is a liquid metal, all metals are solid* at room temperature (20-30°C). They all have characteristic metallic *lustre* and are good *conductors* of heat and electricity. Most of them are *malleable* while some are *brittle.*

Simple substances known as non-metals are made up of non metallic elements in their free state. These are not so closely similar to one another as the metals are under ordinary conditions. Some are gases (chlorine, oxygen, nitrogen), while others are solids (iodine, phosphorus and carbon). Bromine is the only liquid non-metal. Non-metals are poor conductors of heat and electricity.

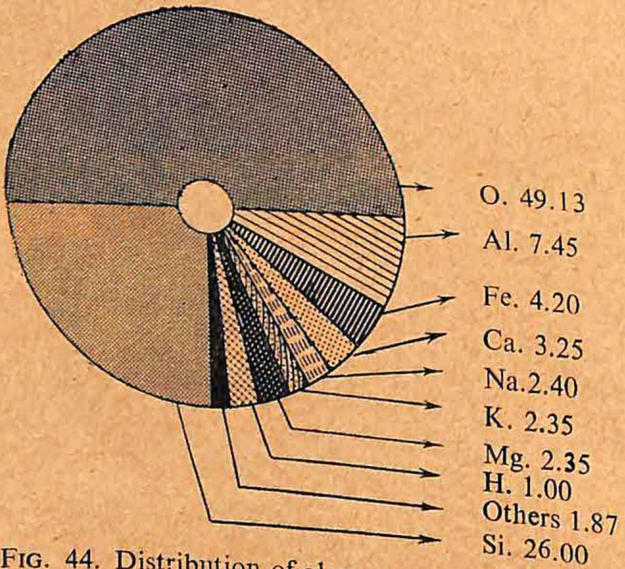


FIG. 44. Distribution of elements in nature

The distribution of chemical elements in nature is shown in Fig. 44.

It can be seen from this diagram that oxygen is the most widespread element in nature. Half of the total weight of all the elements that go to make up the composition of the earth's crust, is due to oxygen.

Oxygen, nitrogen, sulphur, copper, silver and gold are some of the elements found in the free state in nature. Most of the elements in the earth's crust however exist in the form of compounds.

QUESTIONS AND EXERCISES

1. What is a chemical element?
2. Of what elements are the following substances made: (a) copper, (b) oxygen and (c) copper oxide.
3. Two gases, oxygen and hydrogen, are formed on decomposing water by an electric current. Can we say that water consists of two simple substances?
4. Why can we not say that mercuric oxide contains two simple substances, mercury and oxygen?
5. What elements are present in the following complex substances?

   iron oxide, copper oxide, mercuric oxide and water.
6. Some of the following substances contain two elements, others contain only one. State which of them contain one and which contain two:

   copper, iron, iron sulphide, sulphur, cupric oxide, oxygen, water, mercuric oxide and hydrogen.
7. What substances are known to you whose molecules contain one or more of the following elements? copper, sulphur, oxygen, iron, hydrogen.
8. State in which of the above cases are we referring to the molecules of oxygen.

   (a) Oxygen is present in mercuric oxide

   (b) Oxygen is present in cupric oxide

(c) Oxygen was collected in a cylinder

(d) Oxygen is slightly soluble in water

9. Is it correct to say that "A sample of pure ferrous sulphide contains no sulphur in it"? How can the statement be modified so as to make the meaning of the person who made the statement, clear?

15. Symbols of Chemical Elements

On pages 38-39 the schemes of chemical reactions are given. In these schemes atoms of elements are represented by circles. These signs were in use long ago, but the practice was found to be inconvenient, especially when one had to deal with molecules of compounds having a large number of atoms.

In 1914, Berzelius, a Swedish scientist, introduced a new system of representing atoms of the elements by one or two letters of their Latin or Greek names.

The element hydrogen (Latin name hydrogenium) is represented by the letter H. As mercury is called Hydrargirum in Latin, the sign for mercury is written as Hg, to avoid confusion with the sign of hydrogen. An atom of oxygen is represented by the letter O, which is the first letter of the Latin name for oxygen (Oxygenium). Carbon in represented by the letter C from its Latin name carbonium. Since the first letter of Copper (known as cuprum in Latin) is C, as in the case of carbon, copper is represented by the letter Cu to avoid confusion. Such representations are known as symbols of chemical elements.

The symbols of hydrogen, oxygen, carbon, copper and aluminium are H, O, C, Cu, and Al respectively. The symbols used all over the world are the same. A symbol is not merely a sign of an element. It also denotes one atom of the element, and represents that quantity of an element by weight which is equal to its atomic weight.

Thus the symbol Cu means :

1. Chemical element copper.
2. One atom of copper, *i.e.*, 63.5 (64) oxygen units.

Some of the common elements that we usually come across, with their symbols, Latin names and their rounded values of atomic weights are given in the following table :

Symbols, Latin Names and Atomic Weights of Some Elements

Chemical Symbol of the element	Atomic weight	English name of the element	Latin name of the element
Ag	108	*Silver*	Argentum
Al	27	*Aluminium*	Aluminium
Ba	137	*Barium*	Barium
C	12	Carbon	Carbonium
Ca	40	*Calcium*	Calcium
Cl	35.5	Chlorine	Chlorum
Cu	63.5	*Copper*	Cuprum
Fe	56	*Iron*	Ferrum
H	1	Hydrogen	Hydrogenium
Hg	201	*Mercury*	Hydrargirum
K	39	*Potassium*	Kalium
Mg	24	*Magnesium*	Magnesium
Mn	35	*Manganese*	Manganum
N	14	Nitrogen	Nitrogenium
Na	23	*Sodium*	Natrium
O	16	Oxygen	Oxygenium
P	31	Phosphorus	Phosphorus
Pb	207	*Lead*	Plumbum
S	32	Sulphur	Sulphur
Si	28	Silicon	Silitsium
Sn	119	*Tin*	Stannum
Zn	65	*Zinc*	Zincum

Note : Metals are shown in italics

QUESTIONS AND EXERCISES

1. What practice is followed in chemistry to represent the elements ?
2. What do the following symbols represent ? S, Pb, Na, P, Mg.
3. Write down the symbols of the following elements : calcium, carbon, copper, chlorine, silicon, zinc. What does each of these symbols mean ?

16. Chemical Formulae : Molecular Weight

Molecules of simple and complex substances can be represented by symbols of elements. For this purpose it is necessary to know (i) the elements comprising a molecule of the given substance (qualitative composition) and (2) how many atoms of each element are present in the molecule (quantitative composition).

Both of these can be found out by experiments. If you are given a yellow powder of unknown composition, and if on heating it you get only metallic mercury and gaseous oxygen, both of which could be recognized by their properties, it means that the yellow powder is made up of two elements, mercury and oxygen. Thus the qualitative composition of this substance is now known. The next thing to be determined is its quantitative composition, *i.e.*, how many atoms each of mercury and oxygen go to make one molecule. For this purpose a small quantity of the substance is weighed accurately and then heated so as to decompose it completely. The mercury obtained is then weighed. Suppose the original substance weighed 4·33 grammes and the weight of mercury was 4·01 grammes. It follows that the weight of oxygen liberated will be 0.32 grammes. It can now be calculated as to how many parts by weight of mercury are present per every 16 parts by weight of oxygen, *i.e.*, per atom of oxygen. The calculations are as follows :

Wt. of mercury combining with 0.32 parts by wt. of oxygen =4.01 parts by wt.

∴ Wt. of mercury combining with 1 part by wt. of oxygen $= \frac{4.01}{0.32}$ parts by wt.

Hence, wt. of mercury combining with 16 parts by wt. of oxygen $= \frac{4.01 \times 16}{0.32}$,,

$= 200.6$,,

This value 200.6 is corresponding to the atomic weight of mercury. Since a molecule cannot contain less than one atom of an element, it is clear that the given substance contains one atom of oxygen to one atom of mercury.

On this evidence, using the chemical symbols, the composition of a molecule of mercuric oxide can be represented as HgO.

Representation of the composition of a molecule of a substance by chemical symbols is known as **chemical formula.**

Thus HgO is the chemical formula of mercuric oxide.

It has been proved experimentally that two atoms of hydrogen and one atom of oxygen are present in each molecule of water. Hence we can write the formula of water as H_2O.

The number at the lower right of the symbol of an element gives the number of atoms of that element present in a molecule. It is known as the *index*. If there is only one atom of a given element it is not necessary to write the index number after the symbol concerned, as the symbol itself represents one atom. In the case of a simple substance also, the number of atoms present in a molecule is represented by an index written at the lower right of the symbol of the element. As a molecule of oxygen contains two atoms, its formula is written as O_2.

The chemical formula of a substance tells us about:

(1) the atoms of the elements which make up a molecule of the given substance;

(2) the number of atoms of each element present in a molecule of a substance.

If you know the atomic weights of the elements present in a molecule of a given substance, you can calculate the weight of this molecule in terms of oxygen units.

The weight of a molecule in oxygen units is known as its **molecular weight**.

Molecular weight can be determined experimentally. It can be calculated if the formula of a substance is known, as it is equal to the total of the weights of all the atoms present in a molecule of the substance. Thus, the molecular weight of mercuric oxide, HgO, is 216.6 O.U.

200.6	+	16	=	216.6 O.U.
Atomic weight of mercury		Atomic weight of oxygen		Molecular weight of mercuric oxide

Molecular weight is generally represented by the letters Mw.

Molecular weight of water (H_2O) can be calculated as follows :

$$\text{Mw. } H_2O = (1 \times 2) + (16) = 18 \text{ O.U.}$$

We can thus say that a chemical formula denotes not only the composition of a molecule of a substance but also the weight which is equivalent to its molecular weight.

QUESTIONS AND EXERCISES

1. What is a chemical formula ? What does it indicate ?
2. What do you understand by the molecular weight of a substance ?
3. What are the elements whose atoms constitute the following complex compounds ?
   (i) MgO (ii) CuO and (iii) Fe_2O_3.
   Calculate the molecular weights of these substances.
4. Name the elements of which the following are composed :
   (a) Hydrogen chloride (HCl) (b) Quick lime (CaO)
   (c) Sulphur dioxide (SO_2) (d) Sulphuric acid (H_2SO_4)
   (e) Ammonia (NH_3) (f) Potassium nitrate (KNO_3)

(g) Marble ($CaCO_3$) (h) Ammonium chloride (NH_4Cl) and (i) Baking soda ($NaHCO_3$).

5. How will you symbolically represent the following? (a) An atom of sulphur, (b) a molecule of sulphur dioxide, containing one atom of sulphur and two atoms of oxygen, (c) three atoms of sulphur, (d) two molecules of sulphur dioxide.
6. Write down the formulae and molecular weights of (i) hydrogen sulphide containing two atoms of hydrogen, and one atom of sulphur per molecule; (ii) nitrous oxide, containing two atoms of nitrogen and one atom of oxygen per molecule; (iii) nitric anhydride containing two atoms of nitrogen and five atoms of oxygen per molecule and (iv) sodium chloride containing one atom each of sodium and chlorine.
7. Calculate the molecular weights of HNO_3, $AgNO_3$, and H_2SO_4.
8. State whether a molecule of oxygen is heavier than a molecule of water. Explain why?
9. State which is more heavy: 5 molecules of water (H_2O) or one molecule of sulphuric acid (H_2SO_4).

17. The Constancy of the Composition of Substances

When water was electrolyzed (page 34) we observed that the volumes of the gases (hydrogen and oxygen) obtained were not equal. The volume of oxygen liberated was half of the volume of hydrogen produced. For instance, for every litre of oxygen liberated two litres of hydrogen are produced. One litre of oxygen weighs 1·429 grammes whereas one litre of hydrogen weighs 0.089 grammes. From the above we can calculate the proportion by weight of the elements hydrogen and oxygen present in water as shown below:

$$\begin{aligned} &(0.089 \times 2) : 1.429 \\ &= 0.178 : 1.429 \\ &= 1 : 8 \\ &= 2 : 16 \end{aligned}$$

It means that in the molecule of water there is one atom of oxygen (atomic weight 16) for every two atoms of hydrogen (atomic weight 1). Hence the formula of water will be H_2O.

Water, in pure form, can be obtained from different sources: by distillation of natural water, through decomposition of basic carbonate of copper or by other chemical reactions. Whatever be the source, the composition of the molecules of water will always remain the same.

For every atom of oxygen there will be two atoms of hydrogen per molecule of water.

Similar conclusion on the constancy of the composition of the molecules is arrived at by studying the composition of other substances. Thus iron sulphide was obtained (page 36) by heating 4 parts by weight of sulphur and 7 parts by weight of iron. If this proportion is maintained, there will be a complete union of the two substances. If, on the other hand, we take 8 parts by weight of iron instead of 7 parts and 4 parts by weight of sulphur, one part of iron will not be used up in the reaction. Similarly, if we take 5 parts of sulphur and 7 parts of iron, one part of sulphur will remain unreacted. Sulphur and iron unite only in the following proportion by weight.

$$\begin{aligned} 4:7 &= 8:14 \\ &= 16:28 \\ &= 32:56. \end{aligned}$$

Thus in a molecule of iron sulphide, one atom of iron (atomic weight 56) is in combination with one atom of sulphur (atomic weight 32) and hence the formula of iron sulphide is FeS.

From a study of the composition of various substances chemists came to the conclusion that the *proportions by weight in which elements combine to form complex substances are always the same.*

This means that combination between atoms of chemical elements to form a compound takes place only in definite quantitative proportions. The atoms do not combine with one another in any random proportion. It is on the basis of this that we express the composition of molecules of substances by means of formulae.

Chemical compounds differ from mixtures, because the former have a constant composition. The composition of mixtures can however be changed in any manner one chooses. Every pure substance is composed of identical molecules.

> *The ratio between the weights of the elements in any given quantity of a substance is the same as the ratio between the weights of the atoms in one molecule of that substance.*

QUESTIONS AND EXERCISES

1. Explain the constancy of composition of a substance on the basis of atom-molecular studies.
2. In what way do chemical compounds and mixtures differ ?
3. Given that 7 parts by weight of iron combine with 4 parts by weight of sulphur, calculate the amount of sulphur required to convert 105 grammes of iron into iron sulphide.
4. How many grammes of iron sulphide can be obtained by heating a mixture of 7 grammes each of iron and sulphur ?
5. 2.00 grammes of mercury is obtained when 2.16 grammes of a sample of mercuric oxide is decomposed. When 2.63 grammes of another sample of mercuric oxide was decomposed, 2.435 grammes of mercury were obtained. Does the given data confirm the law of constant composition ?

18. Calculation of the Percentage Composition of a Substance from its Formula

If we know the formula of a complex substance, we can calculate the percentages of its constituent elements. Let us take the case of magnesium oxide, MgO, and see how we can calculate its percentage composition.

Molecular weight of $MgO = 24 + 16 = 40$ (O.U.)

$\therefore$ In 40 parts of MgO, the weight of $Mg = 24$ parts.

$\therefore$ In 1 part of MgO, weight of $Mg = \frac{24}{40}$ „

$\therefore$ In 100 parts of MgO, weight of

$$Mg = \frac{24 \times 100}{40} \quad „$$
$$= 60$$

Thus we find that 100 parts of magnesium oxide contain 60 parts by weight of magnesium. Hence the quantity of oxygen present in 100 parts of magnesium oxide will be $100 - 60 = 40$ parts by weight.

Let us take another example and calculate the percentage composition of Aluminium oxide, Al_2O_3.

$$\text{Mw. } Al_2O_3 = (2 \times 27) + (3 \times 16) = 4 + 48 = 102 \text{ O.U.}$$

In 102 parts by weight of Al_2O_3 there will be 54 parts by weight of aluminium.

Hence, in 100 parts by weight of Al_2O_3 there will be $\frac{54}{102} \times 100 = 52{\cdot}9$ parts by weight of aluminium.

Therefore, 100 parts by weight of Al_2O_3 will have 47.1 parts by weight of oxygen.

In other words, the percentage composition of Al_2O_3 will be :

Aluminium = 52.9, Oxygen = 47.1.

Let us consider a third example and calculate the percentage of the element oxygen in water.

$$\text{Mw. of } H_2O = (1 \times 2) + (16) = 2 + 16 = 18 \text{ O.U.}$$

As 18 parts by weight of water contain 16 parts by weight of oxygen, weight of oxygen in one part by weight of water $= \frac{16}{18}$ parts by weight.

Hence weight of oxygen in 100 parts by weight of water $= \frac{16}{18} \times 100 = 88.88$.

The quantity of the element oxygen in water comes to 88.8%.

The calculation of the percentage composition from the formula of a compound substance is of great importance, since it helps in determining the quantity of an element present in it. It also gives us an idea as to how much free element can be obtained from a chemical compound.

QUESTIONS AND EXERCISES

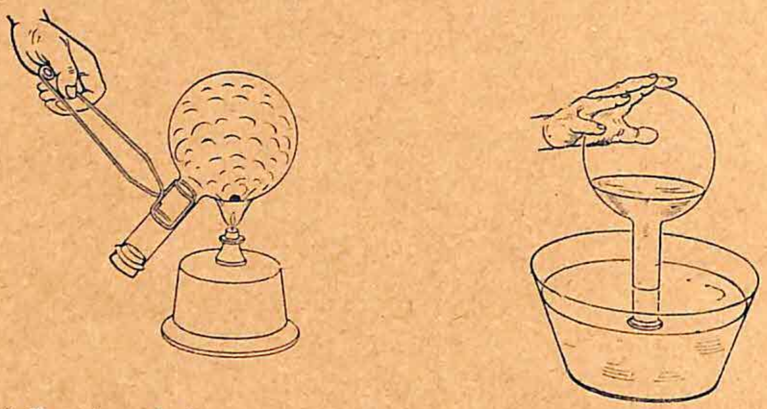
1. From the formulae of mercuric oxide and cupric oxide, calculate how many parts by weight of mercury and copper are present in these compounds for every one part by weight of oxygen. (Answer : 12.5 and 4)
2. In iron sulphide, sulphur and iron are present in the ratio of 4 : 7 by weight. Calculate the percentage composition of the compound.
3. Calculate the percentage of iron present in iron oxide, Fe_2O_3. (Answer : 70% of iron)
4. Calculate the percentage of oxygen in (a) cupric oxide, (CuO), (b) mercuric oxide (HgO). (Answer : (a) 20% (b) 7·4%)
5. Which element is more in copper pyrites, $CuFeS_2$, copper or iron ? (solve the problem orally)
6. In a sample of crude common salt, NaCl, 55% of chlorine was found to be present. What is the percentage of pure sodium chloride present in the sample ?

19. The Law of Conservation of Mass

You have learnt that changes occur in substances during decomposition and combination reactions. Now, the question is whether the mass of the various substances remains constant throughout the transformations or not. The answer to this question may be obtained from the following experiment.

In a small glass flask a very small quantity (of the size of a rice grain) of dry red phosphorus powder is taken. Closing the flask tightly with a rubber stopper, it is weighed accurately on a balance and its weight is noted. The phosphorus is then carefully heated. It catches flame and burns producing a white smoke which fills the whole of the flask. The flask is then cooled by allowing it to stand on an asbestos gauze, and weighed again. It is found that the flask has the same weight as it had before heating.

If the mouth of the flask is now dipped in a trough of water and the stopper removed, water rises inside the flask. Why does this happen?



(a) Burning of phosphorus in flask

(b) Water rises in the flask as a part of oxygen is used up in the burning of phosphorus

FIG. 45. Burning of phosphorus in a closed vessel

Let us conduct another experiment. Take 20 ml. of sodium chloride (NaCl) solution in a conical flask and introduce into it a small test-tube containing silver nitrate solution (Fig. 46). Close the flask with a stopper and find its accurate weight on a balance. Remove the flask from the balance and tilt it carefully so that the two solutions get mixed. A precipitate will be formed at once indicating that a chemical reaction has taken place. After sometime weigh the flask again. It will be seen that no change in weight has taken place.

In weighing we only compare the mass of a body with the mass of a set of weights. In other words, we determine the mass of a body. As the gravitational force acting on all bodies at a given place on the earth is the same, the weights of comparable masses are numerically equal to the masses and hence the terms mass and weight are usually used synonymously.

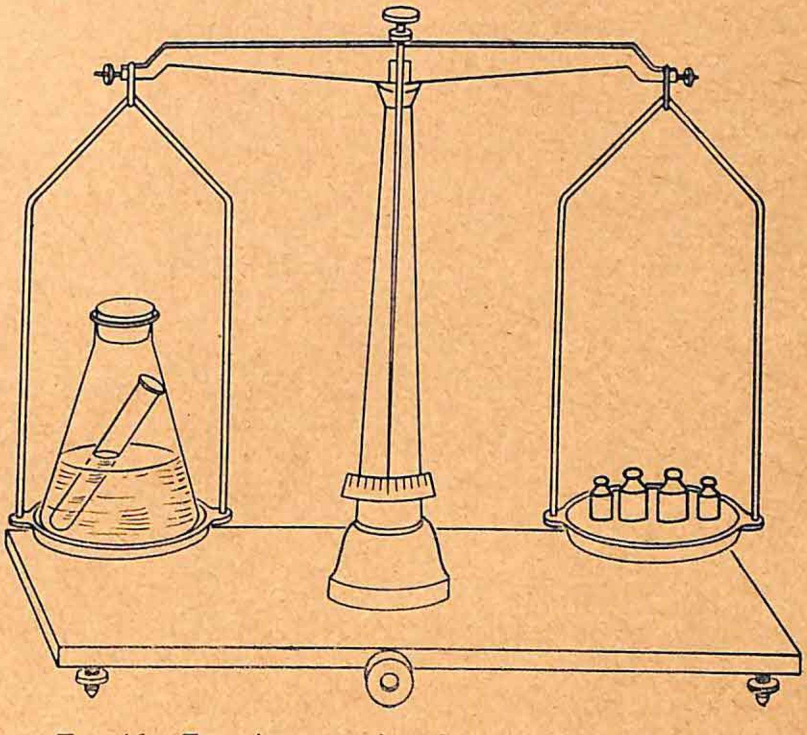


FIG. 46. Experiment to show indestructibility of matter

On investigation of a large number of chemical reactions it has been found that the masses remain constant throughout the reaction, *i.e.*, no change of mass takes place as a result of the chemical reaction.

In the experiment of burning red phosphorus we saw that a part of the oxygen of the air present in the flask combined with the phosphorus to form a new substance, phosphorus pentoxide, which is produced in the form of a white smoke. The molecules of phosphorus pentoxide are composed of the formula P_2O_5. The number of atoms did not change, no new atom is created nor any atom destroyed during this chemical reaction. The total weight of the atoms taking part in the reaction also remained unchanged. Whatever quantity of oxygen was required for the complete combustion of phosphorus was taken up, and the entire quantity of phosphorus was converted into phosphorus pentoxide, assuming that the quantity of oxygen available was more than what was required for complete combustion. If, on the contrary, it was less, then the whole of oxygen would be utilized and the unreacted phosphorus would remain behind. In any case there is no change in the total number of atoms present in the system and hence no change in the mass (or weight) either.

The other experiment conducted by us may also be explained in the same manner. Many hitherto unexplained phenomena could be explained on the basis of the law of conservation of mass. Thus in the case of a burning candle, it would appear that substances vanish without leaving a trace, but if we could collect all the products of the

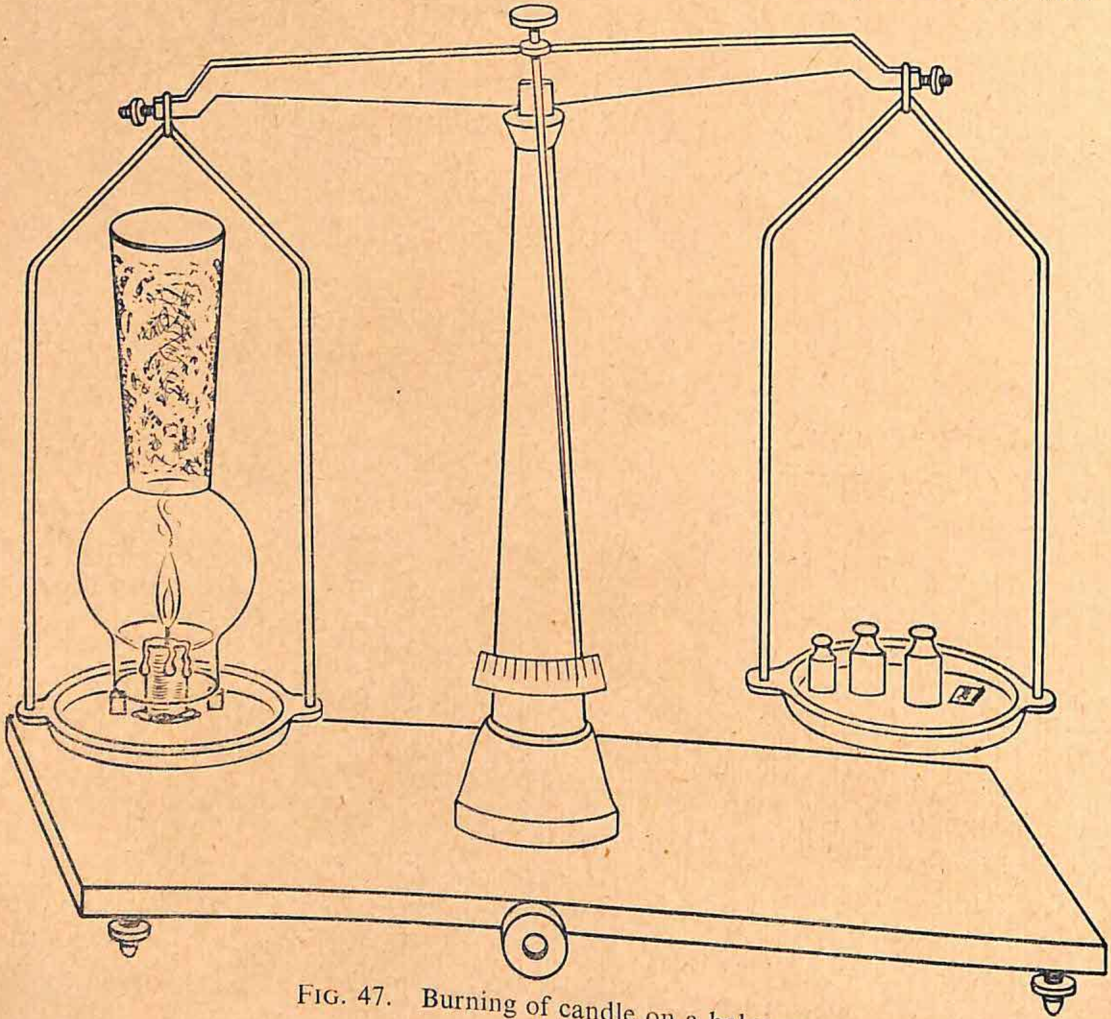


FIG. 47. Burning of candle on a balance

reaction, a true account of this phenomenon would be available. This can be seen by the following experiment (Fig. 47).

A candle is placed in the pan of a balance and is covered by a glass chimney containing a mixture of substances that would completely absorb the products of combustion of the candle, carbon dioxide and water vapour. Weights are employed to counterpoise the candle and the chimney. While burning, the candle decreases in size, but the pan in which it is placed does not go up. On the contrary, it comes down. That means that the products of combustion are heavier than the candle itself. This is because oxygen from the air is used up in the burning of the candle and hence the mass increases with the consequent downward tilting of the balance.

A comprehensive study of several chemical transformations has shown that the total mass of the reactants and products remains constant throughout the transformation.

> *Substances neither disappear without leaving any trace nor can they be produced from nothing. Hence, the mass of substances taking part in a reaction is equal to the mass of substances obtained as a result of the reaction.*

This law of nature is known as the *Law of Conservation of Mass*. The law of conservation of mass is of importance because we can make use of it in writing chemical formulae and equations. We also use it to determine how much of initial substance should be taken in order to obtain the required quantity of products. Such calculations as these are of great significance in the planning of chemical enterprises and consequently in the entire national economy.

QUESTIONS AND EXERCISES

1. What are the experiments by which we can prove that the total weight of a substance remains unchanged by chemical reactions ?
2. State the law of conservation of mass. What is the significance of this law ?
3. Four grammes of mercury were obtained on heating 4.32 grammes of mercuric oxide. What is the quantity of oxygen liberated in the reaction ?

(Answer 0.32 grammes)

4. A small quantity of iron dust was heated in a closed test-tube. The weight did not change on heating. How can it be proved that a part of air has reacted with the metal ?

5. Someone heated a small quantity of iron powder in a weighed test-tube closed with a porous cork. The metal was tarnished. The test-tube was then cooled and again weighed with the cork on. The weight was found to be more than the previous one (*i.e.*, before heating). How can you explain the results of this experiment ?

6. Cupric oxide is formed by

   (1) heating copper carbonate

   (2) heating copper to redness.

   Now the weight of cupric oxide is found to be less than the original substance taken in the first case and more than the original substance taken in the second case. What is the type of reaction that takes place in the two cases ?

7. One gramme of a metallic powder was placed in a tube which was then drawn to a jet and sealed. The tube was then heated strongly in a flame. After cooling, the jet was broken under water and some water rose into the tube. The water entering the tube was carefully (without loss) poured into a measuring cylinder. Its volume was found to be 75 ml. Taking the weight of one litre of oxygen to be equal to 1.43 grammes, determine the sum of the weights of the unchanged metal and its metallic oxide thus formed.

8. 0.16 gramme of oxygen was obtained on decomposing 2.17 gm of mercuric oxide. If no other substance except mercury was formed in this reaction, what is the quantity of mercury thus formed ?

9. What is the quantity of carbon dioxide formed on decomposing 2.21 gm. of malachite, if, on heating it, 1.59 gm of copper oxide and 0.18 gm of water are formed ? (Only copper oxide, carbon dioxide and water are formed in the reaction).

20. Chemical Equation

With the help of the symbols of elements and chemical formulae we can represent the reactants and products of a chemical reaction in a very short form.

For instance, let us write down *the reaction of decomposition of mercuric oxide :*

HgO	$\longrightarrow$	Hg	$+$	O_2
Molecule of mercuric oxide		Molecule of mercury		Molecule of oxygen

It has been shown here that mercury and oxygen are obtained as a result of the decomposition of mercuric oxide. The total number of atoms on the left-hand side is not identical with the total number of atoms on the right-hand side. In a molecule of HgO there is only one atom of oxygen, but for the formation of a molecule of oxygen, two atoms of oxygen are needed. These can come only from two molecules of mercuric oxide, as shown below :

$$2\,HgO = 2\,Hg + O_2$$

Now the total number of atoms on both sides are equal. It is clear that the weight of the substances taken is equal to the weight of the substances obtained. This can be easily verified.

$$\begin{aligned} 2\,HgO &= 2Hg + O_2 \\ 2\,(200.6+16) &= 2\times 200.6+2\times 16 \\ 433{\cdot}2 &= 401.2+32 \\ &= 433.2 \text{ O.U.} \end{aligned}$$

The sign of equality indicates that the total number of atoms of the reactants is equal to the total number of atoms of the products. Thus the total weight of the substances prior to the reaction is equal to the total weight of the substances obtained as products.

The mode of representing a chemical reaction with the help of symbols and formulae is called a **chemical equation**.

The example cited above is that of an equation representing the decomposition of mercuric oxide.

The number preceding the formula of a substance is known as the **coefficient.**

In this case, they show that two atoms of mercury and a molecule of oxygen are produced from two molecules of mercuric oxide. In other equations these numbers may be different. These should not be confused with the indices.

The **indices** *are figures which indicate the number of atoms of elements in the molecule of a substance.*

Let us now see how we can write down the chemical equation for the decomposition of water.

$$H_2O \longrightarrow H_2 + O_2$$

In the above statement the number of atoms in the reactants and the products are not identical, hence we should select suitable coefficients.

Since in a molecule of oxygen there are two atoms of oxygen and since a molecule of water contains only one atom of oxygen, it is clear that we will require two molecules of water.

$$2H_2O \longrightarrow H_2 + O_2$$

Now two molecules of water have four atoms of hydrogen and since a molecule of hydrogen also contains two atoms, we can say that two molecules of hydrogen are produced by the decomposition of two molecules of water.

$$2\,H_2O \longrightarrow 2\,H_2 + O_2$$

In the above statement, the number of atoms of each element on the right-hand side of the arrow is equal to the number of atoms of the same elements on the left-hand side. Now we can replace the arrow by the sign of equality.

$$2\,H_2O = 2\,H_2 + O_2$$

The sign of equality can be used only after the coefficients are selected, otherwise it would not be in conformity with the law of conservation of mass.

Chemical Equations indicate :

(i) the substances that take part in the reaction and those that are produced as a consequence ;

(ii) the quantities of the reactants and the products by weight.

In the reaction of decomposition of water the equation shows that from every 36 parts by weight of water (oxygen units, grammes, kilograms, ton), 32 parts by weight of oxygen and four parts by weight of hydrogen are formed.

For writing a chemical equation, it is necessary to know the formulae of the reactant and the products and to select suitable coefficients. Furthermore, only such equations should be formulated that correspond to a chemical reaction that actually takes place.

QUESTIONS AND EXERCISES

1. What things should be known and what rules must be observed to write a chemical equation ?
2. What does a chemical equation indicate ?

CHAPTER III

Oxygen : Air

OXYGEN

Chemical symbol	O	Atomic weight 16
Molecular formula	O_2	Molecular weight 32

21. Physical and Chemical Properties of Oxygen

We have seen how oxygen was liberated by heating mercuric oxide (page 33). The Swedish scientist Scheele first prepared oxygen in 1771 in the same manner, and then the English chemist Priestley also prepared the gas. Later the French scientist A. Lavoisier studied the properties of this gas and named it 'oxygenium' (oxygen).

For the study of the properties of a substance it should be taken in pure form. For this purpose several substances can be decomposed to give pure oxygen.

Oxygen is a colourless, odourless and tasteless gas. It is slightly heavier than air. Scientists have found out that oxygen at a temperature of 0°C and a pressure of 760 mm of mercury (1 atmosphere) weighs 1.43 gm. The solubility of oxygen in water is about 30 ml per litre. On cooling it intensely, oxygen is converted into a bluish liquid (Boiling point-183°C). It evaporates very fast under normal conditions. We have only enumerated above the physical properties of oxygen. The chemical properties of oxygen depend on its ability to undergo various chemical reactions.

For studying the chemical properties of oxygen, let us collect the gas in a few gas jars.

Fix a piece of charcoal at the end of a copper wire or place it on a deflagrating spoon (Fig. 48) which is used for burning substances. Heat it to red-hot over the flame of a spirit lamp. The charcoal piece starts glowing in the air. Now introduce it into a jar of oxygen. It glows brilliantly and burns out very fast. No flame is, however visible. (Fig. 49 a). In this process, carbon combines with oxygen and liberates large quantity of heat. The equation of this reaction is as follows:

$$C + O_2 = CO_2 + \text{heat}$$

Carbon dioxide is formed as a result of this reaction. The formation of this gas can be confirmed by adding a little lime water into the jar. The lime water turns turbid.

FIG. 48. Deflagrating spoon

Place a little sulphur in a deflagrating spoon, and hold it over the flame of a spirit lamp. When the sulphur melts and just starts burning, introduce the deflagrating spoon into a jar of oxygen. The flame becomes bright, bluish-violet in colour. Like charcoal, sulphur also burns more vigorously in oxygen than in air (Fig. 49 b). On burning, sulphur dioxide is formed which is a product of the union of sulphur and oxygen.

$$S + O_2 = SO_2 + \text{heat}$$

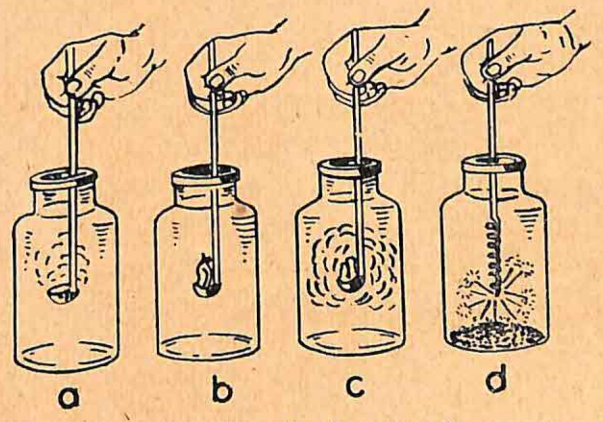


FIG. 49. Burning of substances in oxygen

A large quantity of heat is liberated during the burning of sulphur. Sulphur dioxide can be easily recognized by its pungent and unpleasant smell.

We can also burn phosphorus in oxygen in the same manner. Powder of red phosphorus is burnt in a deflagrating spoon. It burns on exposure to atmospheric air giving a thick white smoke and with a dazzling flame (Fig. 49 c). The smoke is of phosphorus pentoxide. It has the formula P_2O_5. We may write the following equation to represent the reaction.

$$P + 5O_2 = 2P_2O_5 + \text{heat}$$

Magnesium metal also burns in air with dazzling brilliance. But if a burning ribbon of magnesium is introduced into a jar of oxygen, the brightness of the flame increases many times (Fig. 48 d). A white powder, called magnesium oxide, is formed as a result of the combination of magnesium with oxygen.

$$2Mg + O_2 = 2MgO + \text{heat}$$

Many other substances, which we consider as non-combustible, burn in oxygen because they do not burn in air on heating. Even a steel wire, nib or needle can be made to burn in oxygen. For this, a piece of cork may be fixed at the end of a wire or a nib. The cork serves as a handle so that the wire or the nib may be heated without burning the fingers. After heating strongly, if introduced into a jar of oxygen, the wire burns without flame, throwing out glittering sparks in all directions. These are the red-hot grains of iron cinder formed by the union of iron with oxygen. The strong burning of iron cinders shows that a great quantity of heat is liberated in this reaction. Red-hot cinders may break the gas jar. Hence, sand is sprinkled at its bottom before introducing the red-hot iron or steel wire. The composition of iron cinders can be experssed by the formula Fe_3O_4. Its molecule consists of three atoms of iron and four atoms of oxygen.

Experiments have shown that the burning of substances in air is due to the fact that it contains oxygen. But as air is a mixture of gases, substances do not burn in it as vigorously as they do in oxygen. Burning is more vigorous in pure oxygen. The ability to accelerate the burning of substances is an important chemical property of oxygen.

QUESTIONS AND EXERCISES

1. What are the physical properties of oxygen ? Give examples of experiments and observations that confirm its chemical properties.

2. Write the equations of the reaction of burning of sulphur, charcoal, magnesium and phosphorus. To what type do the above reactions belong ?
3. On burning in oxygen, the metals calcium and aluminium produce substances having formulae CaO and Al_2O_3. Write equations to express these reactions.
4. How can you prove that carbon dioxide is obtained by burning charcol in oxygen ?
5. How can you burn a steel needle in oxygen ?

HOME WORK

You have observed the reactions of burning of substances in oxygen. Write down their equations. Underline the formulae of the substances produced and write their names and also the names of elements of which these are composed. What is common in their composition and what is different ?

22. Reactions of Oxidation—Oxides

When simple substances are burnt in oxygen, combination of their elements with oxygen takes place and the products thus formed are known as oxides.

> *Complex substances that are composed of two elements (one of which is oxygen) are called* **oxides**.

Oxygen combines with many elements, metals as well as non-metals. During this process various oxides are formed and heat is liberated in a majority of cases. Many oxides are named simply as oxide of the metal or non-metal concerned, for example, cupric oxide CuO, mercuric oxide HgO. Some oxides are named differently depending on the quantity of oxygen present in them, for example, sulphur dioxide SO_2, carbon dioxide CO_2, phosphorus pentoxide P_2O_5.

Oxides may be solids, liquids or gases under normal conditions. For example, carbon dioxide is a gas, water a liquid and magnesium oxide a solid.

To write down the formula of an oxide, it is necessary to know how many atoms of oxygen and the other element are present in each molecule of the oxide. While studying the composition of aluminium oxide, it has been shown that its molecule contains two atoms of aluminium and three atoms of oxygen and hence the formula of aluminium oxide is Al_2O_3.

Many compound substances can also burn in oxygen and air and oxides are formed in such cases also. Thus the substance methane having two elements, carbon and hydrogen, in its molecule (its formula is CH_4), on burning in oxygen produces two oxides : carbon dioxide and water.

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

The interaction of simple and complex substances with oxygen is called the **reaction of oxidation**.

The ability to oxidize various substances is the most important property of oxygen. Hence it belongs to the group of substances called *oxidizers*, and is one of the most important (active) members of the group. When simple and compound substances are burnt, oxidation takes place. Evolution of heat and light accompanies burning.

Since time immemorial, people have been making use of several substances for obtaining heat. Even the primitive man knew the use of fire. The processes of combustion were unknown and hence was quite a puzzle for a long time. But chemistry has revealed the secrets of burning and it is no longer a riddle.

Burning is a chemical reaction in which oxidation of substances takes place accompanied by the liberation of heat and light.

QUESTIONS AND EXERCISES

1. What are oxides ? Name the substances having the formulae PbO, Fe_2O_3. What do these chemical formulae mean ?
2. Write the formulae of (a) silicon dioxide, each molecule of which consists of one atom of silcon and two atoms of oxygen, (b) sodium oxide, whose molecule consists of two atoms of sodium and one atom of oxygen.

3. Which chemical reactions are called oxidation reactions ?
4. What are the characteristic features of burning ?
5. What products are produced by burning hydrogen sulphide (H_2S) ?

23. Slow Oxidation

In the case of the burning of a simple or compound substance, the oxidation is fast. But in several instances, the oxidation takes place slowly and it is not accompanied by the evolution of heat in the usual manner. Such processes are called *slow oxidation.* Rusting of iron is an example of this. Respiration is another example of slow oxidation. In respiration blood absorbs the oxygen of the air and circulates it through the body. Oxidation of various substances occurs in the organism with the formation of carbon dioxide and other complex substances. Heat is also liberated but the liberation takes place in small quantities, step by step, which keeps the body temperature constant.

Since a small quantity of heat is evolved during slow oxidation, it gets dispersed in the surroundings and we do not often notice the increase in temperature. But in case we are able to prevent the escape of this heat, we can see that a considerable rise in temperature takes place and the substances may even catch fire. For instance, rags used for wiping off oil from machinery, if allowed to lie together in a pile for a long time, may sometimes catch fire by themselves. The reason is that the oil gets oxidized by oxygen present in the air and the heat does not get dispersed quickly. Thus a time comes when the temperature becomes so high as to set ablaze the rags, resulting in a fire. In the same way you can see in a compost pit, where dung and other refuse rot to form manure, that considerable heat is evolved due to slow oxidation of substances. If one puts the hand deep inside the compost the heat is felt and may even cause blisters.

The study of the process of slow oxidation has great significance. Its knowledge enables us to control such harmful phenomena as rusting of metals, spontaneous ignition of substances, spoiling of food products, etc. The heat produced by slow oxidation finds a wide use in agriculture. A layer of dung is spread under the soil of seed-beds in nurseries and hot houses. The dung decomposes due to oxidation by the oxygen of the air. The heat produced thereby warms up the soil which facilitates germination.

Exothermic and Endothermic Reactions

You have already seen that when substances like carbon, phosphorus, iron, sulphur, etc., burn in oxygen, energy is liberated in the form of heat and light. On the other hand, there are reactions in which energy is absorbed. For example, in the decomposition of mercuric oxide, heat is absorbed, not liberated.

> *Chemical reactions in which heat is liberated are called* **exothermic reactions**. *Chemical reactions in which heat is absorbed are called* **endothermic reactions**.

Burning is an exothermic process. The energy obtained by burning coal, wood, oil and other fuels is used in our daily life and industrial processes.

Heat is produced not only during burning and slow oxidation but also in many other chemical reactions and this is one of the important features of chemical reactions.

QUESTIONS AND EXERCISES

1. What examples of the processes of slow oxidation are known to you ?
2. How is the process of slow oxidation important to man and animals ?
3. In what way does burning differ from rusting and respiration ?
4. Write the equations of exothermic and endothermic reactions known to you.

24. Oxygen in Nature

Oxygen is the most wide-spread element on the earth. Its weight is almost half of the earth's crust including its solid, liquid and gaseous envelope. (see Fig. 4 on page 46).

Oxygen is present in air with other gases, the most important of which is nitrogen. In combination with other elements it forms a large part of rocks and soil, plants and animals. Common sand is only an oxide of the element called silicon and contains 69 per cent of oxygen. In water its percentage is as high as 88.88. A good amount of oxygen, in the form of a simple substance, is also present in water in the dissolved state. On an average, about 40 gms of dissolved oxygen are found to be present in one cubic metre of natural water.

Oxygen is very important to all living beings as it is needed for respiration. Without oxygen, life on earth would have been impossible. It has been estimated that man, even at rest, breathes in about 16 gms of oxygen per hour, and requires much more oxygen while at work. Fish and other aquatic animals breathe in oxygen that is dissolved in water. Plants also inhale oxygen. Only certain microbes can exist without it. Oxygen takes part in the formation of soil. Oxygen also actively participates in the decomposition of animal and vegetable remains. New substances formed in this process remain in the soil and are absorbed by the plants for their nourishment. Thus we see how great a role is played by oxygen in various processes of transformation of substances in nature.

25. Uses of Oxygen

The role of oxygen is very significant in the process of burning. Combustion of fuels produces heat which is converted into mechanical, electrical and other types of energy. For obtaining high temperatures in the smelting of cast iron and steel, an additional quantity of oxygen combined with air is blown into a blast furnace, which not only accelerates the smelting of the metal but also improves its quality.

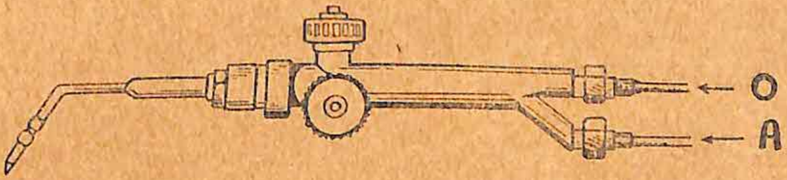


FIG. 50. Oxy-acetylene burner
O-oxygen, A-acetylene

If some inflammable gas is burnt in pure oxygen, a flame with very high temperature is obtained. In Fig. 50 is shown a burner, by which such high temperatures are attained by burning acetylene (an inflammable gas) in pure oxygen. The gases are kept under pressure in steel cylinders from which they enter the burner. The temperature reached in an oxy-acetylene flame is about 3,000°C. Iron and other metals melt in it. This flame is utilized to cut steel plates, weld together steel pipes, girders, etc. (autogenous welding). The processes of cutting, welding, etc. can be carried out even under water, with this flame. This is of great importance in many under-water constructions. Oxygen also finds wide uses in many branches of chemical industry, like the production of acids and other important chemicals. Oxygen is also used in hospitals, under-water swimming, mountaineering, high altitude travel and in fire-fighting. In all these cases it is used to enable the person concerned to breathe when he is otherwise unable to do so or when there is an insufficient supply of air or oxygen available for breathing purposes. Liquid oxygen or air is used for producing low temperatures.

26. Methods of Preparation of Oxygen

Small quantities of oxygen may be obtained from potassium permanganate which is a violet crystalline solid soluble in water. Let us see how oxygen can be obtained by this method.

EXPERIMENT

Fix a test-tube containing about one gramme of potassium permanganate on a stand and heat it by a spirit lamp. As the oxygen coming out contains fine dust, which irritates the organs of breathing, do not smell the oxygen coming out. Avoid touching the wick of the flame with the test-tube so that it may not crack (Fig. 51).

As oxygen is only slightly soluble in water, it is possible to collect it over water (Fig. 52). A gas holder is used for storing oxygen and other gases in the laboratory.

Before filling the gas holder with oxygen, it is filled with water by means of a funnel. When this is being done, the tap of the upper tube is kept open. Then both the upper taps are closed, the lower stopper is removed and the delivery tube from the apparatus is inserted through the opening to allow the oxygen to enter the holder

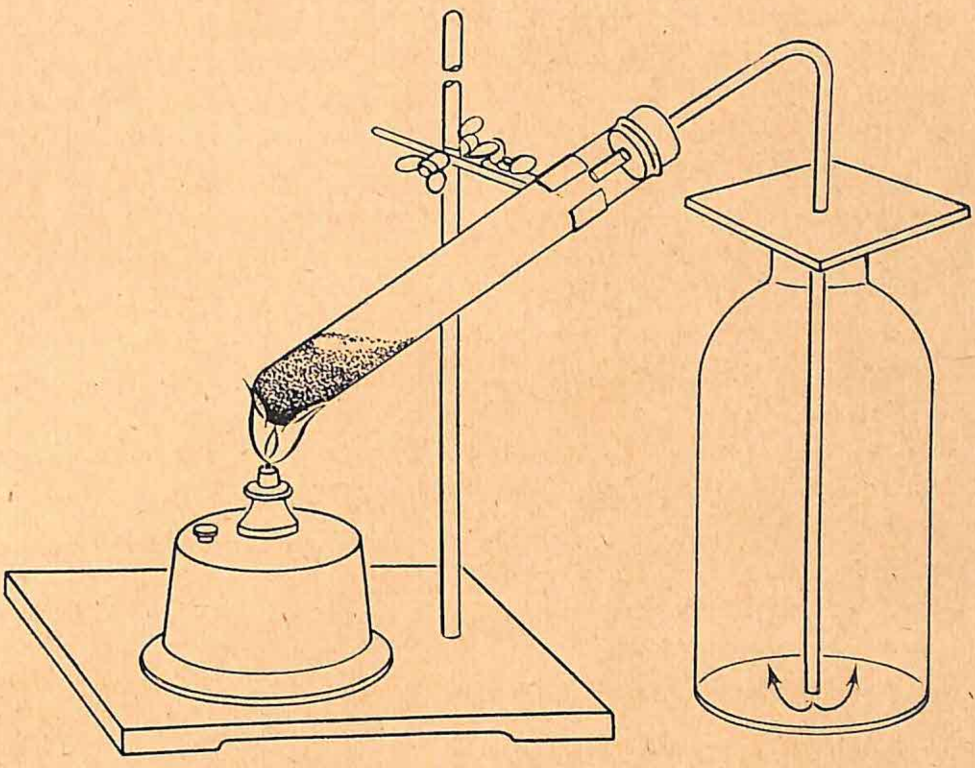


FIG. 51. Preparation of oxygen from potassium permanganate

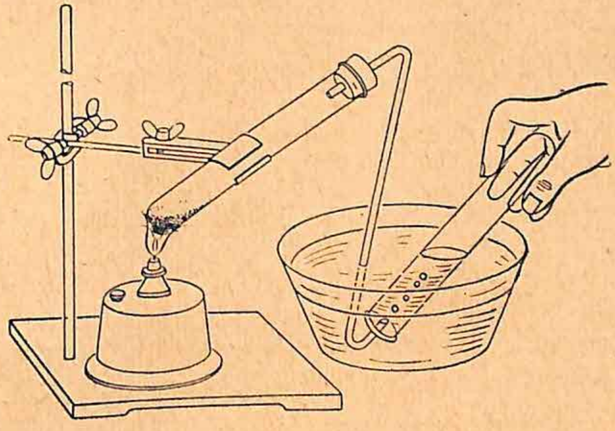


FIG. 52. Collection of oxygen over water

(Fig. 53). Oxygen gas starts rising up by displacing water from the gas holder. The water flows out through the lower opening. When the gas holder is filled with oxygen, the lower opening is closed with a stopper. Oxygen can be stored for a long period in a gas holder.

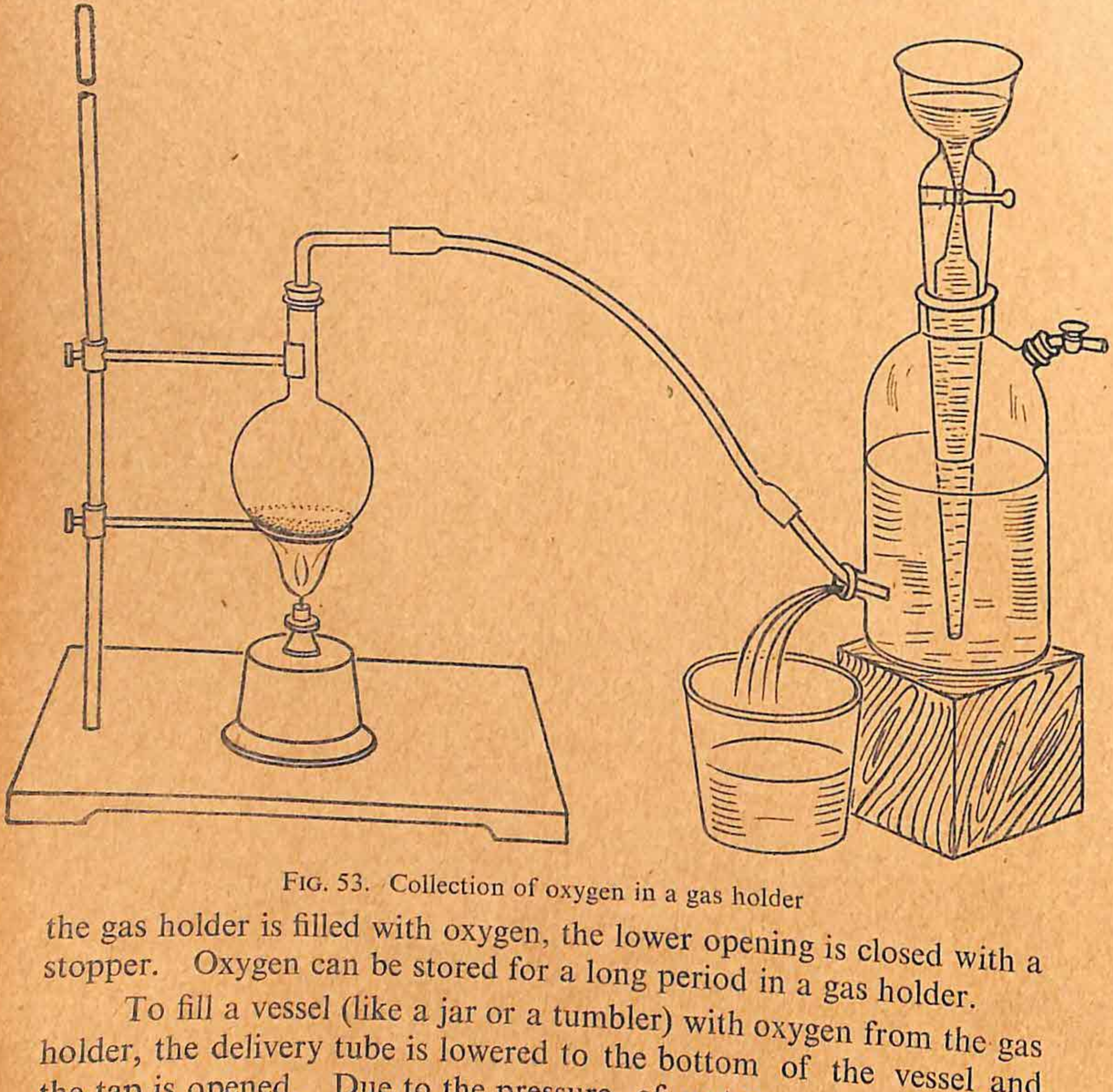


FIG. 53. Collection of oxygen in a gas holder

To fill a vessel (like a jar or a tumbler) with oxygen from the gas holder, the delivery tube is lowered to the bottom of the vessel and the tap is opened. Due to the pressure of water coming out of the funnel into the bottle, the oxygen is pushed out of the gas holder into the vessel.

In the laboratory small quantities of oxygen may be prepared from potassium chlorate, which is a white crystalline powder, having the formula $KClO_3$. Potassium chlorate must be handled with care, because in the presence of inflammable impurities, it explodes due to friction or striking. On heating, potassium chlorate melts in the beginning and then appears to boil. This is an indication of the beginning of the decomposition of the salt and the formation of oxygen which can be tested with the help of a smouldering splinter.

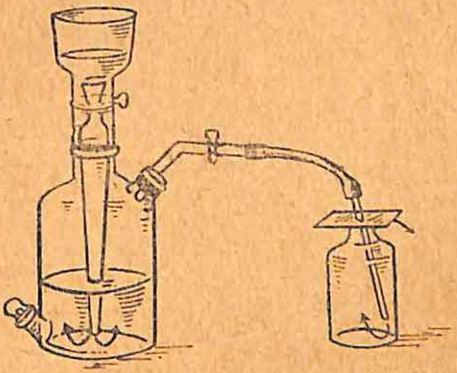


FIG. 54. Filling oxygen in a vessel from the gas holder

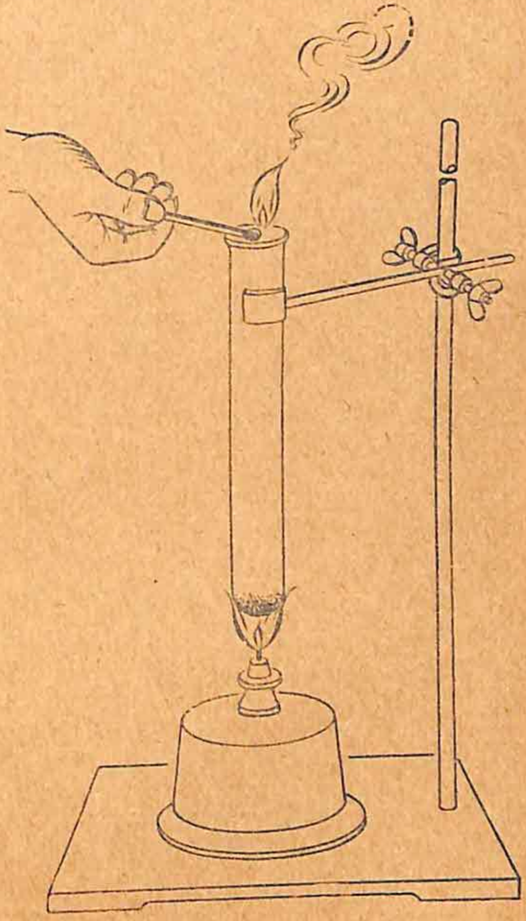


FIG. 55. Testing oxygen with a smouldering splinter

On heating potassium chlorate, oxygen and potassium chloride are obtained. The equation of this reaction can be written as follows:

$$2KClO_3 = 2KCl + 3O_2$$

By adding a small amount of black powder of manganese dioxide, MnO_2, potassium chlorate can be made to decompose, giving out oxygen at a considerably faster rate. If, in the above experiment, a little manganese dioxide is added to the melted potassium chlorate in the test-tube, the rate of evolution of oxygen is increased at once.

The total quantity of manganese dioxide remains unchanged in this process. One can say that it is not at all consumed in this process. It can be used for decomposition of a further quantity of potassium chlorate. On the other hand, if a little manganese dioxide is heated not very strongly in a test-tube without potassium chlorate, no oxygen is evolved. This shows that manganese dioxide has the property of increasing the speed of the reaction of decomposition of potassium chlorate, but itself remains chemically unchanged throughout the process, *i.e.*, its composition and original properties are preserved.

A substance which changes the speed of a reaction but itself remains chemically unchanged throughout the reaction, is known as a **catalytic agent.**

Manganese dioxide is a catalytic agent which accelerates the decomposition of potassium chlorate. Many different catalytic agents (or catalysts) are known today. They are of great importance to the chemical industry, as they increase the rate of reactions.

On an industrial scale oxygen is obtained from air. You will learn more about this in higher classes. It is also obtained by the electrolysis of water. For the transportation and storage of oxygen it is pumped into steel cylinders under a pressure of about 150 atmospheres. At this pressure, 5 kilogrammes of oxygen can be stored in a cylinder of 25 litres capacity. Large quantities of oxygen in liquid form can be stored and transported in metallic oxygen 'tanks'. For storage of small quantities of liquid oxygen in laboratories,

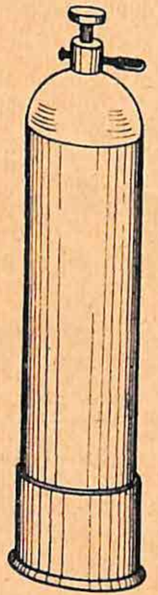


FIG. 56.
Oxygen Cylinder

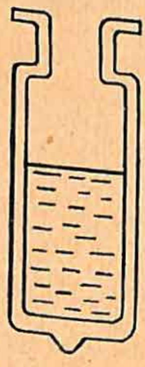


FIG. 57.
Dewar's flask

glass vessels called Dewar's flasks (constructed like glass thermosflasks) are employed.

QUESTIONS AND EXERCISES

1. In what form do we find oxygen in nature ?
2. In what way is oxygen significant for the life of men, animals and plants ?
3. Give a brief account of the processes in which oxygen is used.
4. From what substances and under what conditions can you get oxygen in the laboratory ?
5. Which property of oxygen is used for its collection in jars and gas holders ?
6. State the conditions under which the decomposition of potassium chlorate takes place. Write the equation to represent the reaction.
7. Potassium chlorate and manganese dioxide are heated together to obtain oxygen. What is the role of manganese dioxide in the reaction ?
8. What is a catalytic agent.
9. How is oxygen obtained on a large scale ?
10. Calculate the percentage of oxygen present in potassium chlorate. Basing your calculation on the result obtained, find out how much of the substance should be taken to obtain 10 litres of oxygen. (One litre of oxygen weighs 1.43 grammes.)
11. What is the weight of oxygen present in 50 grammes of water ?

LABORATORY WORK

Preparation and properties of oxygen

Equipment : A spirit lamp, a wooden stand with test-tubes, a hard glass boiling tube with a rubber stopper fitted with a delivery tube, a trough, 3 gas jars with lids, deflagrating spoon, test-tube holder, metal stand.

Reagents and materials : water, splinters, potassium permanganate, sulphur, charcoal, lime water.

Procedure : 1. *To fill the jars with oxygen by displacement of air and to burn charcoal in oxygen.*

The apparatus is assembled as shown in Fig. 58. Fill 1/5 part of a test-tube with potassium permanganate, and fix it on a stand at such a height that the delivery tube almost touches the bottom of the jar in which oxygen is to be collected. The jar is covered by a piece of cardboard. First, the whole of the boiling tube is heated carefully by a flame and then the part containing the potassium permanganate is heated strongly.

Moving the cardbord lid a little to one side, a smouldering splinter is inserted into the jar, taking care that it is not lowered more than one centimeter into the jar. When the splinter burns brightly at the mouth of the jar, remove the delivery tube from the jar and cover the jar with a lid.

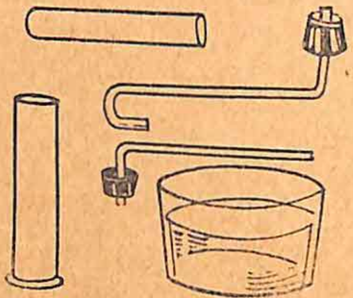


FIG. 58.

Heat a piece of charcoal to red-hot in a deflagrating spoon and insert it into a jar containing oxygen. Observe how it burns. Do you see a flame ? Extinguish the burning charcoal with water. Now add a little lime water into the jar and shake it. What happens ? What is the substance that is formed by burning charcoal in oxygen ?

2. *Collection of oxygen gas over water and burning of sulphur in oxygen.*

Assemble the apparatus for obtaining oxygen, as shown in Fig. 52. Fill one-fifth of the boiling tube with potassium permanganate and close the mouth of the tube with a cork fitted with a delivery tube. Now fix the test-tube on a stand. Take some water in a trough. Fill the jars, in which oxygen is to be collected, with water and cover them with lids. Invert one of the jars in the trough of water and remove the lid.

Heat the potassium permanganate as in the previous experiment and test the gas coming out of the delivery tube by means of a smouldering splinter, which catches fire. (why ?). Now take the end of the delivery tube under the water in the trough and introduce it into the mouth of the inverted jar. Continue the heating of potassium permanganate, while holding the jar with your hand. Bubbles of oxygen rise up in the jar and get collected in it while the water is displaced. First remove the delivery tube from the trough and then stop heating the potassium permanganate. Heating must not be stopped before removing the tube from water, because water may be sucked into the hot test-tube and break it.

Covering the mouth of the jar by means of a lid, remove it from the trough and place it on a table without removing the lid.

Heat a little sulphur in a deflagrating spoon till it catches fire and then introduce it into the jar of oxygen. Note how it burns.

Take out the deflagrating spoon and dip it in water to extinguish the burning sulphur. Now pour some water into the jar in which sulphur was burnt and cover it with a lid.

Write the equation for the reaction of burning sulphur in oxygen.

What inferences regarding the physical and chemical properties of oxygen can you draw on the basis of the experiments you have conducted ?

27. Air

Composition of Air

All around the earth there is a gaseous jacket which is known as the atmosphere. It is composed of several gases. We can say that we are living at the bottom of a deep ocean of gases.

Air is essential for all living beings for survival. Man cannot live even for a few minutes without air. Ancient philosophers of Greece, India, and China had written about the importance of air for life. But because air is invisible, and also colourless, odourless and tasteless, it remained almost unstudied by the scientists.

In 1756 M.V. Lomonosov established that a part of air combined with metals on their being heated in air to redness. In 1774 Lavoisier investigated the basic components of air and gave names to them.

Lavoisier heated a little mercury in a retort for a long time on a brazier (some sort of a *sigri*, a vessel or tray carrying hot coals) in order to determine the composition of air. The curved end of the retort was inserted under a bell jar placed in a bowl filled with mercury (Fig. 59). In the beginning no change was noticed. But the very next day Lavoisier observed that a reddish coloured powder was being formed on the surface of mercury in the retort and the mercury level in the bell jar was rising. This continued for 12 days after which the formation of the reddish powder ceased and the level of mercury rose to about one-fifth of the capacity of the bell jar and became stationary. On testing the residual gas in the bell jar with a burning candle, it was found that the candle was extinguished. Mice placed in this gas were killed. The residual gas was therefore named by him as Azote (nitrogen) meaning unsuitable for life.

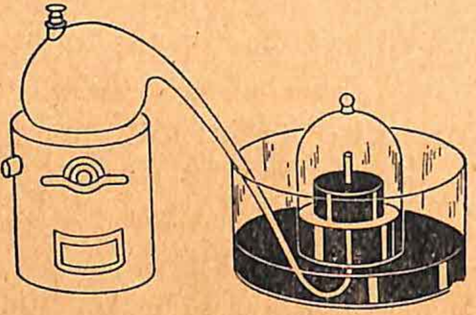


FIG. 59. Lavoisier's experiment to determine the composition of air

Lavoisier collected the reddish powder from the surface of mercury and heated it strongly, when metallic mercury and a gas capable of supporting burning better than air, were obtained. The volume of the gas obtained was found to be equal to that of the volume of mercury that rose in the bell jar. This gas was given the name of oxygen. When oxygen and the remainder of the gas under the bell jar were mixed, air was again obtained. This was in no way different from the normal air. Thus the French chemist was able to establish experimentally that air was basically composed of two gases, nitrogen and oxygen.

HOME WORK

Answer the following questions after carefully going through the account of Lavoisier's experiment.

1. What was the substance that was formed on the surface of mercury in the retort ? Write the equation to represent the reaction of its formation.

2. When this substance was removed and heated strongly what change did it undergo ? Write the equation to represent the change.

3. Why did the formation of the red powder stop on being heated for a long time ? Why did the level of mercury rise by about one-fifth of the capacity of the bell jar ?

It has since been established that air contains small quantities of other gases and various impurities. We can get an idea of the contents of air from the following experiment.

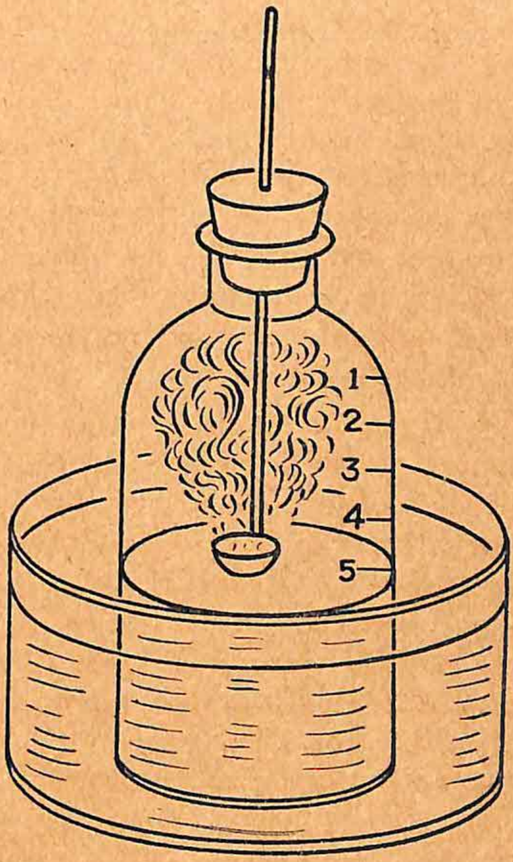


FIG. 60. Burning of phosphorus in bell jar

A bell jar closed with a rubber stopper (Fig. 60) is placed in a large trough containing water. The capacity of the bell jar above water is divided into five equal parts. A deflagrating spoon containing a little phosphorus is then passed through the stopper into the bell jar. The stopper is removed for a moment from the bell jar, the phosphorus is lighted and the stopper is replaced tightly. Phosphorus continues to burn brightly in the jar giving off a thick white smoke of phosphorus pentoxide. The smoke subsides gradually and the bell jar becomes transparent. The burning stops when the whole of the oxygen present in the air enclosed in the bell jar is used up. The water inside the bell jar rises and at the end of the experiment it is found that it has risen by one-fifth of the capacity of the ball jar above original water level. This is equal to the volume of oxygen present in the air contained in the bell jar.

When a burning splinter is inserted into the bell jar, it is extinguished, showing thereby that the gas, that remains behind in the bell jar after the removal of oxygen, does not support combustion.

This gas is nitrogen accompanied by impurities of certain other gases which also do not support combustion. It has been shown by a study of air that the quantity of some gases present in it remains constant, whereas the quantity of some other gases varies. Moreover, there may be various other impurities in air depending on the locality. The variable components of air are, carbon dioxide (about 0.03 per cent) and water vapour. All the components retain their individual properties in the air.

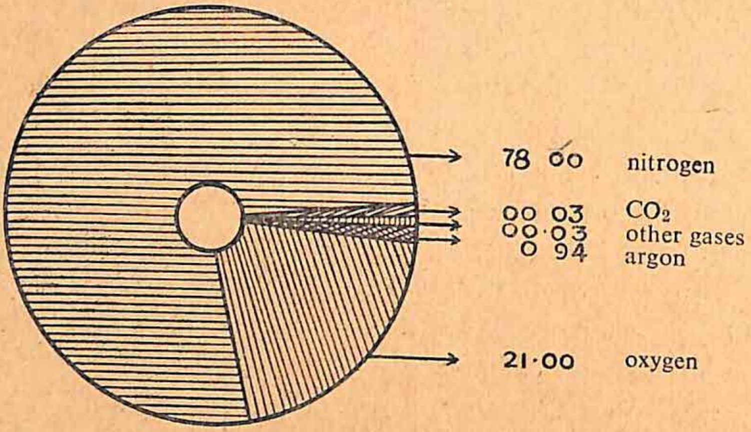


FIG. 61. Percentage composition of air

28. Air is a Mixture of Gases

If we take the constituents of air separately and mix them together in their relative proportions, then air could be obtained in an artificial way. In this process of mixing, neither a chemical reaction takes place nor new substances are formed. The local impurities of air may be in the form of dust, gases, smoke given out by factory chimneys or gases formed in nature, for example, during the process of putrefaction or volcanic eruptions. These gases might include sulphur dioxide, methane, ammonia and others. These are the impurities that pollute the air. Many of them are harmful to plants, animals and human beings. Hence, in the premises of factories, special filters, absorbers, etc. are installed, so that they may keep off the harmful gases, dust, smoke, etc. from mixing into the atmospheric air.

Since air is vitally important to human beings, it is necessary that every care should be taken to maintain its purity in residential areas and public places. The quantity of carbon dioxide and water vapour in the air in a room increases considerably, if many people happen to remain in the room for a long time. Increase in carbon dioxide content to 3 per cent (100 times more than the normal) turns the air entirely unfit for breathing. Therefore, it is essential to provide for regular ventilation of the premises.

Plants play a significant role in freeing the air from carbon dioxide as in the process of manufacturing their food (photosynthesis). The plants absorb carbon dioxide from the air and give out oxygen. The planting of greenery in big towns and its protection are therefore very important for the preservation of the purity of air. The air in the mountains and over the surface of big reservoirs of water is purer. Air in pine woods is pure and healthy for breathing purposes. It is practically free from dust and moreover the slow oxidation of pine-tar produces certain gaseous and volatile substances which are good for the health of people.

Properties and uses of liquid air

On intense cooling at a high pressure, air can be liquefied. Before liquefaction, it is freed from dust, moisture and carbon dioxide. Liquid air is a bluish liquid. The basic constituents of liquid air are liquid oxygen and liquid nitrogen. Liquid oxygen evaporates only after liquid nitrogen does. Separation of oxygen and nitrogen are effected by making use of this property. Air is liquefied and evaporated when nitrogen comes off first and is collected. Almost all oxygen remains as a liquid at this temperature.

Large quantities of nitrogen obtained from the air are utilized for the preparation of nitric acid, fertilizers, explosives, plastics, etc.

Assignments for independent work

Prove the presence of carbon dioxide in some of your surroundings like classroom or living room or club, etc. Get a little powdered lime from a nearby construction site. Otherwise heat a few small pieces of chalk (or better take pieces of marble) to redness on an *angithi* or a stove. On heating, chalk (or marble) turns into lime. Put the lime powder in a bottle, pour some boiled water into it, shake it well, put on the cork and let it stand for a day or two. Then without disturbing the residue, decant the solution carefully into a small phial and test the solution by blowing exhaled air into it through a rubber or glass tube. If the solution turns turbid, then the lime water is ready for use. The carbon dioxide from the air is passed into a phial containing about 50 ml. of lime water by means of a rubber spray (Fig. 62). Compare as to which places, that you had selected, have more carbon dioxide in the air. When you blow the air into it, note how many times you have to press the bulb of the sprayer before the lime water turns milky.

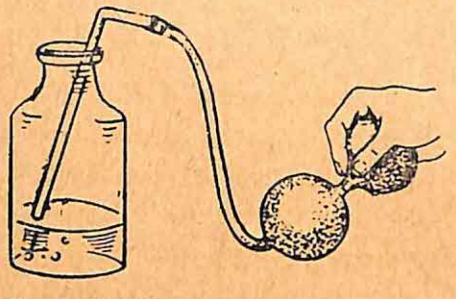


FIG. 62. Blowing carbon dioxide into lime water

QUESTIONS AND EXERCISES

1. How can the oxygen content of air be determined?
2. What are the constant and variable constituents of air? What local impurities can be present in air?
3. State briefly the experiments carried out by Lomonosov and Lavoisier to study the composition of air.
4. What is the percentage composition of oxygen and nitrogen (by volume) in air?
5. In what way is air important in life and technology? Give its practical importance.
6. If one cubic metre of oxygen weighs 1.43 kilogrammes, calculate the weight of oxygen present in the air in your classroom.
7. Given that the specific gravity of liquid oxygen is 1.14, find out how many litres of gaseous oxygen are obtained on evaporating 0.5 litres of liquid oxygen at 0°C at normal atmospheric pressure

(1 litre of gaseous oxygen weighs 1.43 grammes under these conditions).

29. Valency of Elements in Chemical Compounds

Assignment

Recapitulate what you have learnt in section 17 (The Constancy of the Composition of Substances). Write down the formulae of the following oxides : water, calcium oxide, aluminium oxide, carbon dioxide. State how many atoms of each element exist in the composition of the molecules of these substances.

From the molecular formula of water one can see that a molecule of water contains two atoms of hydrogen and one atom of oxygen. Similarly, in a molecule of calcium oxide, there is one atom each of calcium and oxygen, and in a molecule of aluminium oxide there are three atoms of oxygen and two atoms of aluminium. In the molecule of carbon dioxide two atoms of oxygen are combined with one atom of carbon.

From the above examples it can be seen that the atoms of each chemical element have the property of combining with other atoms, not in any haphazard manner, but in certain definite proportions of the atoms concerned.

> *The property of an atom of a chemical element to unite with a definite number of the atoms of other elements is known as* **valency.**

The word valency has originated from the Latin word *valentia* which means power. By this 'power' we mean the property of an element to combine with other elements. The magnitude of valency is expressed by numbers when we compare the number of hydrogen atoms which enter into combination with one atom of the other element to form a compound.

The valency of hydrogen has been chosen as the unit of measurement of valency. Hydrogen in its compound with other elements does not combine with more than one atom of the other elements for every atom of hydrogen. Elements of which one atom combines with one atom of hydrogen to form a compound are called monovalent, *e.g.*, chlorine and bromine are monovalent in their compounds HCl and HBr.

In a molecule of water two atoms of hydrogen are combined with one atom of oxygen. This can be written as H_2O or $H_2{}^{I}O^{II}$. Hence the valency of oxygen is two and from this we can determine the valency of elements in their oxygen compounds. For example, in sodium oxide, one atom of oxygen is combined with two atoms of sodium to form Na_2O, which means the valency of sodium in this compound is one, since one atom of oxygen has a valency of two in terms of the hydrogen unit, ($Na_2{}^{I}O^{II}$). As one atom of it combines with one atom of oxygen, the valency of calcium in calcium oxide is equal to two $Ca^{II}O^{II}$. Atoms with a valency of two are called divalent.

Atoms of chemical elements have valency only when they form compounds with one another. The valency of atoms of the elements in simple substances is taken as zero. For example, the valency of hydrogen or oxygen in H_2 or O_2 is zero. The valency of copper in a piece of copper is also zero. If, however, copper is heated in oxygen, cupric oxide is formed.

$$2Cu + O_2 \rightarrow 2Cu^{II}O^{II}$$

In this compound the valency of copper is equal to two since in a copper oxide molecule there is one atom of copper combining with one atom of oxygen, the valency of which in all its compounds is equal to two.

QUESTIONS AND EXERCISES

1. What is valency ? What is the reason for accepting the valency of hydrogen as the unit ?
2. How can the valency of an element in its compounds with oxygen be determined ?
3. What is the valency of the elements in the following substances ? (i) copper oxide, (ii) copper, (iii) aluminium oxide, (iv) water.
4. The composition of phosphine is expressed by the formula PH_3. What is the valency of phosphorus in this compound ?

30. Determining the Valency of Elements according to the Formulae of their Compounds

If the formula of an oxide is known, the valency of the atoms of the elements present in an oxide can be determined. The formula of magnesium oxide is MgO. Now the valency of oxygen in all its compounds is two. In a molecule of magnesium oxide, for every atom of oxygen there is one atom of magnesium. Therefore the valency of magnesium is also equal to two. In the case of carbon dioxide, its formula is CO_2. Here we see that for every atom of carbon, two atoms of oxygen are present. Since the valency of oxygen is two, the total number of valency units contributed by oxygen will be four $(2\times2=4)$. These units of valency belong to one atom of carbon, therefore the valency of carbon in this compound is four.

Aluminium oxide has the formula Al_2O_3. We can proceed, as follows to find out the valency of aluminium in this compound. The valency of oxygen is two and there are three atoms of oxygen in a molecule of aluminium oxide. Therefore the total units of valency contributed by oxygen will be $2\times3=6$. Between two atoms of aluminium there are six units of valency and therefore each atom of aluminium will have a valency of $(6\div2=3)$ three. Similarly, we can say that iron has a valency of three in iron oxide, whose molecular formula is Fe_2O_3.

In phosphorus pentoxide (P_2O_5), there are five atoms of oxygen, contributing ten units of valency. As against this, there are only two atoms of phosphorus. Hence for each phosphorus atom, there are five units and thus the valency of phosphorus in this compound is equal to five.

From the examples given above we can derive a simple rule of determining the valency of elements in the compounds having two elements.

> *The number of units of valency of all the atoms of one element in a molecule must be equal to the number of units of valency of all the atoms of the other element.*

Let us determine the valency of the element manganese in its compound with oxygen : Mn_2O_7. The number of units of valency contributed by the atoms of the two elements must be equal. Now seven atoms of oxygen contribute 14 units : $(2 \times 7 = 14)$ and since there are only two atoms of manganese in a molecule of Mn_2O_7, the valency units contributed by each atom will be $14 \div 2 = 7$. Hence the valency of manganese in the above compound is equal to seven.

For determining the valency of elements in compound with some elements other than oxygen and hydrogen, one should know the valency of one of the elements. Sulphur in its compounds with metals generally has a valency of two, chlorine in compounds with metals has always the valency of one. With this information and with a knowledge of the rule mentioned above, one can determine the valencies of metals in their compounds with sulphur and chlorine. For example, let us determine the valency of aluminium in aluminium sulphide, Al_2S_3. The valency of sulphur is two. There are three atoms of sulphur and therefore the total valency contribution of these will be $2 \times 3 = 6$ units. Now there are two atoms of aluminium in a molecule of Al_2S_3 and therefore each atom will have a contribution of $6 \div 2 = 3$ units. Hence the valency of aluminium is three in the compound Al_2S_3. Similarly in magnesium chloride, $MgCl_2$, the valency of magnesium will be equal to two.

The following points may be remembered while defining the valency of an element.

1. Valency is always represented by a whole number.
2. The value of valency of an element never exceeds eight.
3. If there are only two atoms in a molecule of a compound, their valencies are identical.

For example, in sodium chloride (NaCl), one atom of sodium combines with one atom of chlorine and the valencies of both sodium and chlorine are equal to one. Again, in zinc oxide (ZnO), one atom of zinc is in combination with one atom of oxygen, and hence the valencies of both zinc and oxygen are equal to two. The valency of sulphur in its compounds with metals is two and hence the valency of iron is two in ferrous sulphide (FeS), since in this compound one atom of iron combines with one atom of sulphur.

31. Variable Valency

The different methods of calculating the valency of elements in compounds discussed above can be made use of only in those cases where a substance is composed of two elements. More complex cases involving more than two elements will be learnt by you later on.

Many chemical elements have different valencies in different compounds. Thus copper combines with oxygen to form the black cupric oxide (CuO). This is a compound known to you. In this compound copper has a valency of two because in CuO, one atom of oxygen having valency two is combined with one atom of copper.

Now copper also forms another compound with oxygen having the formula Cu_2O, a red coloured powder. In this case the valency of copper is one because in Cu_2O, one atom of oxygen having valency two is combined with two atoms of copper.

Iron is another element which forms more than one compound with oxygen. For example, it forms ferrous oxide (FeO) and ferric oxide (F_2O_3). In FeO, the valency of iron is two ($Fe^{II}O^{II}$) whereas in Fe_2O_3, the valency of iron is three ($Fe_2^{III}O_3^{II}$). In the first case one atom of iron combines with one atom of oxygen while in the second case two atoms of iron combine with three atoms of oxygen. Hence the valency of iron in the first case will be two and in the second case three.

Sulphur forms two compounds with oxygen : $S^{IV}O_2^{II}$ and $S^{VI}O_3^{II}$, and the compound $H_2^{I}S^{II}$ with hydrogen. Here the valency of sulphur has been shown to be different in different compounds.

Copper, iron, sulphur and several other elements have different magnitudes of valency (*variable valency*) in different compounds. Many elements like hydrogen, oxygen and some metals have only one value of valency (*constant valency*) in their compounds. A table of the valency of some elements in their compounds is given on next page.

	Name of the element	Value of valency in compounds	Examples of compounds
Elements with constant valency	Hydrogen	1	HCl, H_2O
	Sodium	1	$NaCl$, Na_2O, Na_2S
	Potassium	1	KCl, K_2O
	Silver	1	$AgCl$, Ag_2O
	Oxygen	2	CaO, H_2O, CO_2
	Magnesium	2	$MgCl_2$, MgO
	Calcium	2	$CaCl_2$, CaO
	Zinc	2	$ZnCl_2$, ZnO
	Aluminium	3	$AlCl_3$, Al_2O_3
Elements with variable valency	Sulphur	2, 4, 6	H_2S, SO_2, SO_3
	Copper	1, 2	Cu_2O, CuO
	Iron	2, 3	FeO, Fe_2O_3
	Mercury	1, 2	Hg_2O, HgO
	Phosphorus	3, 5	PH_3, P_2O_5
	Manganese	2, 3, 4, 6, 7	MnO, Mn_2O_3 MnO_2, MnO_3 Mn_2O_7
	Nickel	2, 3	NiO, Ni_2O_3

Using the above table, we can write the formulae of several chemical compounds. It is not necessary to memorize the valency of all elements. It will be enough in the beginning, to remember the value of the valency of a few elements like oxygen, hydrogen, magnesium, calcium, sodium, etc., in their compounds.

Variable valency of elements in their different compounds is generally indicated by using the endings (also known as suffixes) '*ous*' or '*ic*' after the name of the element. In the case of a compound in which the element has a lower valency, the suffix '*ous*' is added, for example, ferr*ous* oxide, cupr*ous* chloride, mercur*ous* iodide, etc. In the valency of the compounds in which the valency of the element is higher, '*ic*' is added as ferr*ic* oxide, cupr*ic* chloride, mercur*ic* iodide, etc.

QUESTIONS AND EXERCISES

1. What are the rules to be followed for calculating the valency of elements in a compound containing two elements ?

2. What are the valencies of the elements in the following oxygen compounds ?

   SiO_2, BaO, Al_2O_3, PbO_2, NaO.

3. In the following compounds of aluminium, it has a valency of three. Determine the valencies of the elements present :

   AlI_3, Al_2S_3, $AlCl_3$ and AlN.

4. If chlorine is univalent in the following compounds, what are the valencies of the other elements present in them ?

   $FeCl_3$, $SbCl_3$, PCl_5, PCl_3 and CCl_4

6. Write the formulae of the oxides of the following elements, the valencies of which are given in brackets after their names.

   Silicon, Si (4); chlorine, Cl (6); Iron, Fe (2) Vanadium, V (5); Tin, Sn (4) and Sodium, Na (1).

7. Give three examples each of elements showing (i) constant valency in their compounds, (ii) variable valency in their compounds. Write the formulae of the oxides of these elements using the table given on page 92.

8. If you know that hydrogen has valency one (monovalent or univalent) and oxygen has a valency two (bivalent or divalent) write down the elements which are (a) monovalent, (b) divalent, (c) trivalent, (d) tetravalent, (e) pentavalent and (f) hexavalent in the following compounds :

   Na_2O, HCl, Cl_2O, PH_3, FeO, CrO_3, MgO, NO_2, TiO_2 As_2O_5.

32. Compilation of the Formulae of Compounds according to the Elements Forming these Substances

Using the rules given above, and that of the table on page 92, we can make the formulae of different compounds. For the present let us take the case of substances consisting of two elements only. It is worth remembering that the formula of a compound can be compiled only by determining its composition. We use the known values of valency for writing the formulae of only those compounds already known in chemistry.

For example, suppose we are to write the formula of a compound of zinc with chlorine. As per table on page 92 zinc shows a constant valency of two in its compounds and chlorine in its turn shows only a valency of one in its compounds with metals. Hence one atom of zinc must combine with two atoms of chlorine to form zinc chloride and thus its formula will be $ZnCl_2$.

If we are required to write the formula of iron oxide, and if we already know that iron in this compound has a valency of three, we shall first write their symbols together : FeO (iron oxide contains only iron and oxygen). But in this formula iron does not show a valency of three. Let us therefore start by writing the valencies of the elements concerned on the top right-hand corner of the symbol of the element, $Fe^{III}\,O^{II}$. Now since atoms of both elements should contribute the same total number of units of valency, two atoms of iron ($2 \times 3 = 6$) and three atoms of oxygen ($3 \times 2 = 6$) should be present in a molecule of iron oxide. Hence its formula becomes Fe_2O_3.

Now let us take the case of oxide of arsenic in which the latter has a valency of five. As before, let us write the symbols of the two elements side by side with their valencies on the top right-hand side of the symbol, $As^{V}\,O^{II}$. Since atoms of both elements should contribute the same total number of units of valency, we can now write the formula of arsenic oxide as As_2O_5.

It is not always necessary to show the value of the valency of an element by a Roman numeral written at the top of its symbol, since one should be able to remember these simple calculations easily.

It must be remembered that one should not think of composing a formula just according to one's free will. It should truly represent the composition of a substance which must have a definite existence. In other words, formulae are used to represent only real compounds and not hypothetical ones, just as a chemical equation can be used only to represent a reaction that actually takes place.

QUESTIONS AND EXERCISES

1. What are the rules to be observed while writing the formulae of substances ?
2. Write the formulae of the following substances, given that the valency of sulphur is two and that of carbon is four.

   Compound of carbon and chlorine
   ,, ,, carbon and sulphur
   ,, ,, zinc and sulphur.
3. Write the formulae of the compounds of oxygen with silver and of barium with tin (valency of silver=1, barium=2 and tin=4).
4. If the valency of phosphorus is three and silicon four in their compounds, compile the formulae of compounds of : (i) calcium with phosphorus, (ii) calcium with chlorine and (iii) calcium with silicon.
5. The following chlorine compounds are formed by phosphorus : PCl_3 and PCl_5. Write down the formulae of oxygen compounds of phosphorus in which it has the same valency as shown in the chlorine compounds given above.

CHAPTER IV

Hydrogen

HYDROGEN

Chemical symbol—H
Atomic weight—1.008
Molecular formula—H_2
Molecular weight—2.016

33. Preparation of Hydrogen

As early as the 18th century it was observed that the action of sulphuric acid on certain metals leads to the formation of a gaseous inflammable substance. Because of its ability to burn, it was named 'inflammable air'. In 1766, the 'inflammable air' was shown to be a new substance, as it produced water on burning. It was, therefore, given the name hydrogen (in Latin hydrogeneum means that which produces water).

We have already seen that hydrogen is obtained by the electrolysis of water. Oxygen is also produced at the same time in this process.

When dilute hydrochloric acid or sulphuric acid is added to a few pieces of zinc in a test-tube, a vigorous reaction takes place and hydrogen is liberated. If a burning splinter is brought near the mouth of the test-tube, the gas starts burning (Fig. 63). When the liberation of hydrogen ceases, a few drops of the liquid from the test-tube are taken on a glass plate and carefully evaporated by holding the plate high over a flame (Fig. 64). A white residue called zinc chloride or zinc sulphate, is obtained. It has the formula $ZnCl_2$ or $ZnSO_4$.

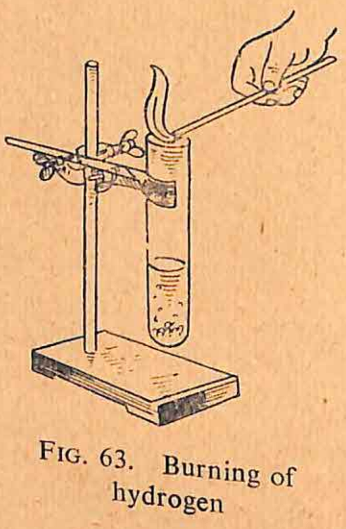


FIG. 63. Burning of hydrogen

Let us now write the equation for the reaction taking place between zinc and hydrochloric acid.

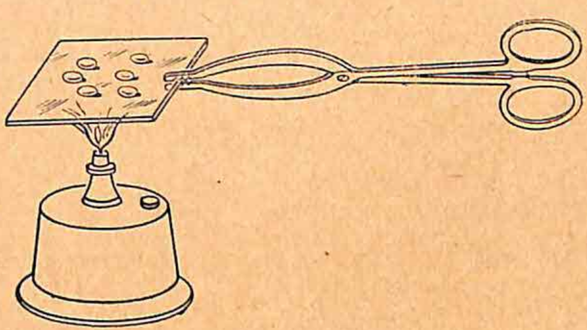


FIG. 64. Evaporation of drops of liquid

Zn	+	2HCl	=	$ZnCl_2$	+	$H_2\uparrow$
zinc		Hydrochloric acid		Zinc chloride		Hydrogen

Some simple apparatus for the preparation of hydrogen are shown in Fig. 65. In these, the reaction between zinc and the acid continues until one of the reacting substances is completely used up. We can however make use of another apparatus, which will enable us to stop the reaction when we so desire (Fig. 66).

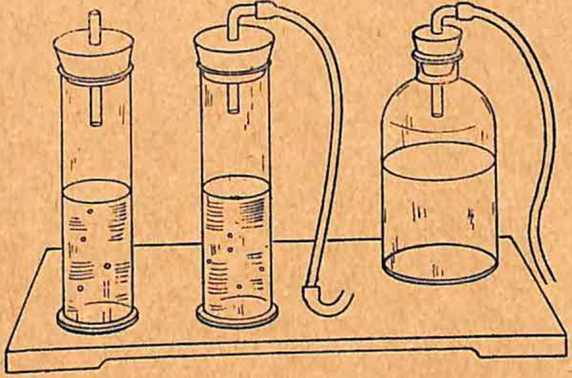


FIG. 65. Hydrogen generating apparatus

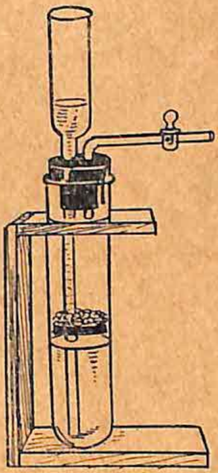


FIG. 66. Another hydrogen generating apparatus

In the laboratory, hydrogen can be obtained by using Kipp's apparatus (Fig. 67). This consists of two bulbs (A and D) and a big globe-like funnel (B) having a long tail. At the opening (C) of the bulb (A), a delivery tube with a stopcock is fitted on a rubber stopper. Some glass balls are introduced first into the bulb (A) through the opening (C). Metallic zinc is now put in the middle bulb by removing the stopper carrying the delivery tube. Keeping the stopcock of the delivery tube open, dilute acid is poured through the globe-like funnel till it is sufficient to cover the pieces of zinc. The acid reacts with the zinc pieces liberating hydrogen, which first expels the air in the middle bulb and then starts escaping through the delivery tube. The stopcock in the delivery tube is then closed. The liberated hydrogen pushes down the acid from the middle bulb to the lower bulb and from the latter into the globe-like funnel, as it has now no way to escape. Thus the acid is kept out of contact with the zinc pieces and the reaction stops temporarily. When hydrogen is needed, it can be obtained by opening the stopcock of the delivery tube. The gas present in the middle bulb passes out through the delivery tube. The acid from the lower bulb then rises into the middle bulb, reacts with the zinc pieces and hydrogen is again liberated. The opening (D) in the lower bulb serves to remove the liquid waste. The apparatus may be kept charged for a long time and hydrogen obtained whenever required.

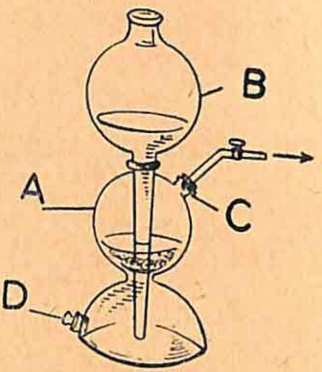


FIG. 67. Kipp's Apparatus

A—Globe
B—Bulb funnel
C—Opening for gas
D—Base opening

QUESTIONS AND EXERCISES

1. Name the substances used in the laboratory to obtain hydrogen. Which of these are simple and which are compound substances ?
2. What other substances can be used to obtain hydrogen ?
3. How will you show that zinc chloride is also produced, besides hydrogen, by the action of hydrochloric acid on zinc ?
4. Explain the construction and working of the Kipp's apparatus.

34. Physical Properties of Hydrogen

Hydrogen is a colourless and odourless gas, nearly insoluble in water. It is liquefied at a very low temperature (—252.8°C) and at —259.2°C it is turned into a snow like mass. To show that hydrogen is lighter than air, we may conduct the following experiments.

EXPERIMENT

Two flasks of equal weight are placed on the pans of a balance so that one exactly counterpoises the other. Now inverting one of the flasks, hydrogen is passed into it (Fig. 68). The hydrogen displaces the air in the flask and gets filled in it. After sometime, the pan with the flask will move upwards. What does this experiment show ?

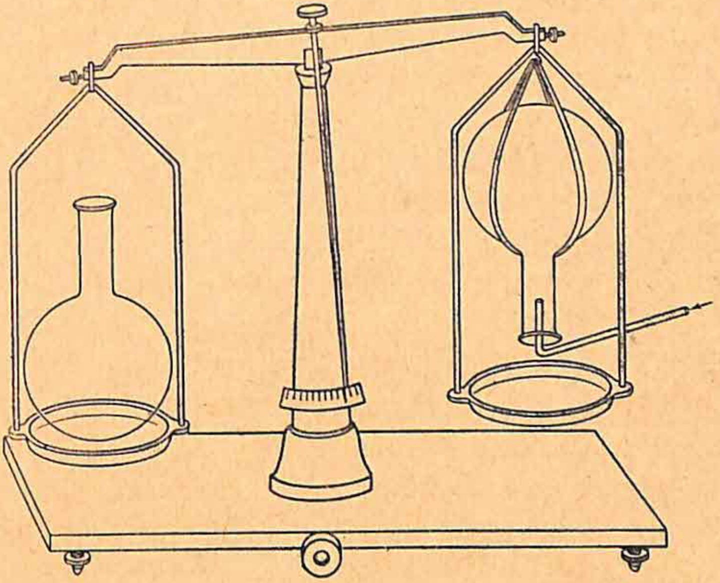


FIG. 68. Weighing a flask with hydrogen

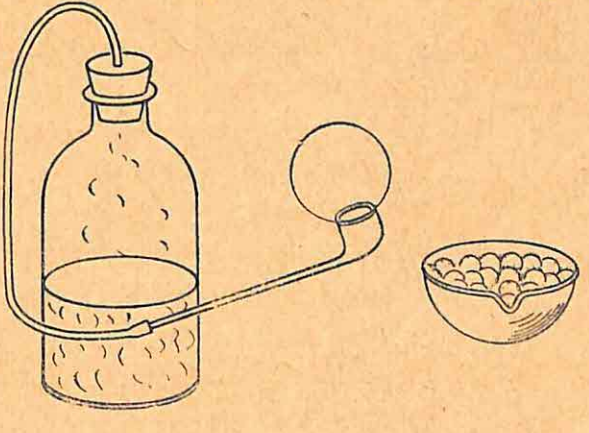


FIG. 69. Soap bubbles filled with hydorgen

Soap bubbles filled with hydrogen (obtained by passing hydrogen through a wide tube of smoking pipe and dipping the other end of the tube in soap solution and shaking the tube to cut off the bubbles that appear) fly upwards (Fig. 69).

Hydrogen is the lightest gas known. It weighs only 0.89 grammes per litre under normal conditions, and hence vessels are filled by the gas, by inverting them and passing hydrogen, when it displaces the air downward and gets filled in them (Fig. 70). Hydrogen can also be collected by the downward displacement of water, as in the case of oxygen (Fig. 71).

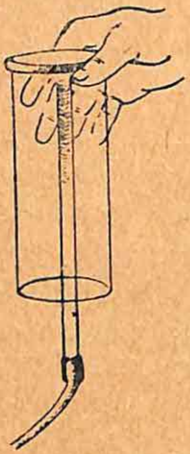


FIG. 70. Lightness of hydrogen

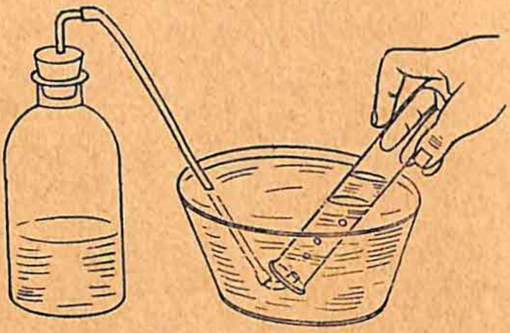


FIG. 71. Collection of hydrogen over water

QUESTIONS AND EXERCISES

1. What are the most important physical properties of hydrogen ?
2. What experiments can you perform to show that hydrogen is lighter than air ?
3. If one litre of air weighs 1.29 gm, calculate how many times hydrogen is lighter than air.

   (Answer : 14.5 times)
4. Compare the physical properties of hydrogen and oxygen and point out the similarity and the difference between them.

35. Chemical Properties of Hydrogen

Hydrogen is an inflammable gas. Let us find out how it burns under different conditions. For this purpose let us take two cylinders or test-tubes. Fill one of them with hydrogen by the downward displacement of water. Take a mixture of hydrogen and air in the other cylinder or test-tube by filling it with water up to half its capacity and then displacing the water with hydrogen.

Now bring the mouths of both the cylinder or tubes to a flame. Pure hydrogen burns quietly with a light blue flame, whereas the mixture of hydrogen and air explodes.

Now let us see what happens when a mixture of hydrogen and pure oxygen is burnt. **This experiment should be performed by the teacher only**. For this purpose a glass bottle with a broad neck or a milk bottle may be used. Measure the capacity of the bottle and divide it into three equal parts which can be marked by a glass pencil or a paper label. Fill the bottle with water and then wrap it with a towel as a precautionary measure. Fill it with one part of oxygen and two parts of hydrogen, by the displacement of water and then close its mouth with a stopper. Remove the stopper and bring the mouth of the bottle quickly near the flame. A powerful explosion takes place and the flame is put off. A mixture of two parts of hydrogen and one part of oxygen is known as '*detonating gas*'.

FIG. 72. Explosion of hydrogen

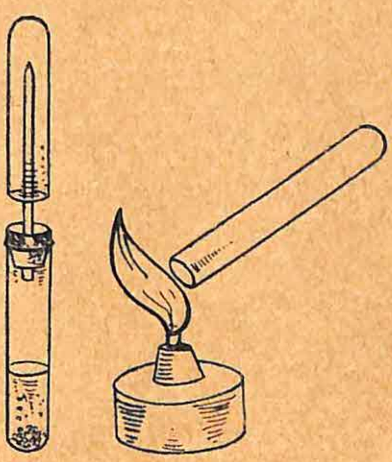


FIG. 73. Burning of hydrogen

The explosion of the mixture of hydrogen and air is of lesser intensity because the oxygen in air is diluted with nitrogen, which does not take part in the reaction under these conditions. *Mixture of hydrogen with oxygen or air must be handled with great care lest accident should take place.* Before igniting hydrogen coming out of the delivery tube of the generating apparatus, it should always be *tested for its purity.*

The purity of hydrogen is tested by collecting it in a test-tube and bringing the mouth of the test-tube near a flame (Fig. 73). If an explosion takes place with a sharp whistle like sound, it shows that the hydrogen is mixed with air. In such a case fire must not be brought near the delivery tube of the generating apparatus till all the air is expelled from it. This is done by filling another test-tube with hydrogen and igniting it when it will burn quietly. Now it is safe to ignite the hydrogen coming out of the delivery tube, when it burns giving out a click-like sound accompanied by a flame appearing at the opening of the delivery tube.

EXPERIMENT

Take a few granules of zinc in a test-tube and add a little dilute hydrochloric acid. Close the mouth of the test-tube with a stopper carrying a glass tube drawn into a jet at the top (Fig. 73). Fix the test-tube on a stand. Collect the hydrogen coming out of the tube and test its purity. If found pure, ignite the hydrogen coming out of the tube. Observe the flame of hydrogen. Now cover the flame carefully with a glass tumbler, or beaker, and hold it in that position for a few moments. What do you observe ?

The above experiment shows that water is formed on burning hydrogen. Very small drops of water are formed on the walls of a vessel held over the flame of burning hydrogen. If this flame is made to impinge on a

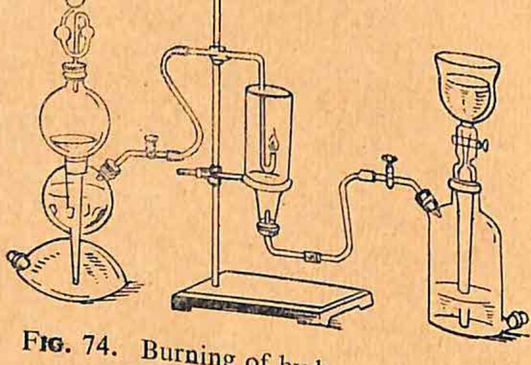


FIG. 74. Burning of hydrogen in oxygen

cold object (a metallic tumbler), droplets of water can be seen trickling down from it.

Hydrogen burns more vigorously in pure oxygen than in air. If a flame of hydrogen is brought into a jar of oxygen it becomes brighter. Drops of water are formed on the walls of the jar.

We can write the equation for the reaction of hydrogen burning in air or oxygen as :

$$\underset{\text{Hydrogen}}{2H_2} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Water}}{2H_2O}$$

This is an example of a reaction of oxidation. It takes place during the explosion of the mixture of hydrogen and oxygen (or air). When hydrogen is mixed with oxygen, the former is oxidized and the product of oxidation is water.

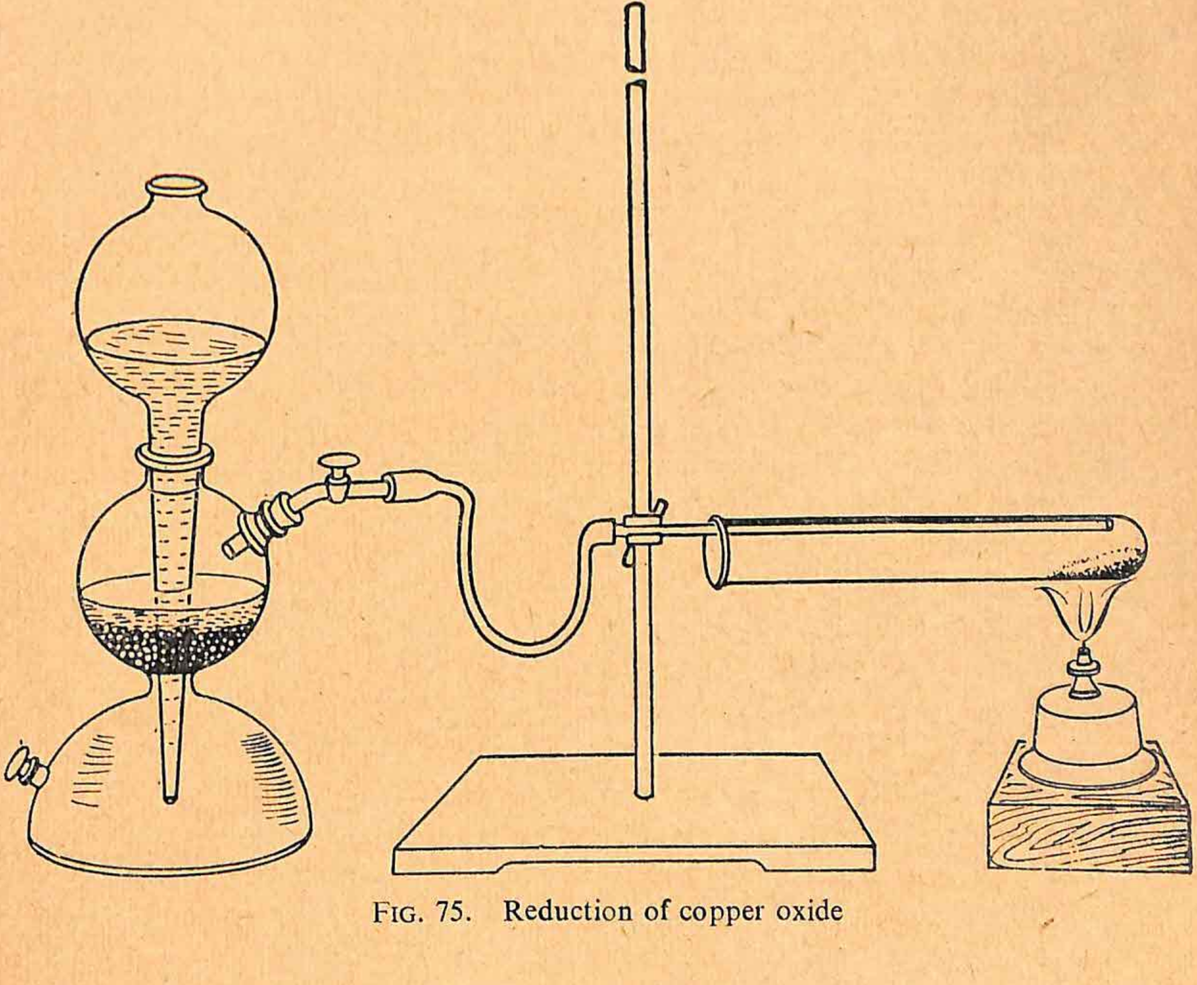


FIG. 75. Reduction of copper oxide

Hydrogen reacts with other elements like chlorine, sulphur and nitrogen and also with several other compound substances.

If hydrogen is allowed to pass over heated cupric oxide in a test-tube, metallic copper will be obtained in the form of a reddish powder and drops of water can be seen collecting on the cooler parts of the test-tube. In this reaction metallic copper is liberated from its oxide. The equation of this reaction can be written as :

$$\underset{\text{Copper oxide}}{CuO} + \underset{\text{Hydrogen}}{H_2} = \underset{\text{Copper}}{Cu} + \underset{\text{Water}}{H_2O}$$

Reactions in which an element is liberated from the oxide compounds are called **reduction reactions** *and substances with the help of which reduction reactions take place are called* **reducing agents.**

Hydrogen acts as a reducing agent in several reactions. If hydrogen is passed over heated lead oxide, water and metallic lead are obtained.

$$\underset{\text{Hydrogen}}{H_2} + \underset{\text{Lead oxide}}{PbO} = \underset{\text{Water}}{H_2O} + \underset{\text{Lead}}{Pb}$$

Hydrogen can reduce a number of other metallic oxides also. Hence this reaction is used in industry for obtaining certain rare metals. Hydrogen is also used for preparing *Vanaspati* ghee from oils.

QUESTIONS AND EXERCISES

1. What are the important chemical properties of hydrogen ?
2. How will you test the purity of hydrogen ?
3. What are the conditions under which hydrogen reacts with oxygen ?
4. How can you obtain water from hydrogen ? Write the equation for this reaction.
5. What is the difference between water and detonating gas ?
6. How can we differentiate oxygen from hydrogen ?

7. Show how can you devise an experiment to illustrate that only oxygen of the air is used up when hydrogen is burnt in it.
8. Name some compound substances with which hydrogen reacts and what are the products formed in these reactions ?
9. What are reduction reactions ? Give examples.
10. *What do you mean by the term 'reducing agent' ?* Give one example of a reducing agent.
11. What is the use of hydrogen in industry ?

36. Distribution of Hydrogen in Nature—Applications of Hydrogen

Only negligible quantities of free hydrogen are found in the atmosphere. But in the combined form hydrogen constitutes about 11 percent by weight of water. It is also present in many minerals, vegetable and animal matter, coal, petroleum and natural inflammable gases.

Hydrogen is found in combination with other gases liberated in volcanic eruptions and from the bore-holes drilled for extractions of petroleum. In the cosmos there is a lot of free hydrogen. The hydrogen atoms present in the whole universe is much larger than the number of atoms of all the other elements put together. It is known that more than half of the mass of the sun consists of hydrogen.

Because of its characteristic properties, hydrogen is used in a number of industries. Since it is the lightest of all the gases, it was used to fill air balloons and air-ships. Now-a-days, however, a non-inflammable mixture of helium and hydrogen is employed instead of pure hydrogen since the latter is inflammable.

On burning, hydrogen produces large quantities of heat. This property is made use of in oxygen-hydrogen flames which can attain a temperature of 2500°—3000°C and hence can be used for cutting and welding metals.

QUESTIONS AND EXERCISES

1. Name the important industries in which hydrogen is used.
2. What property of hydrogen is used in obtaining metals from their oxides ?
3. *Methane, a component of natural gas, has the* formula CH_4. Calculate the percentage of hydrogen *in this compound.* (Answer : 25 per cent)
4. What property of hydrogen is utilized in the cutting and welding of metals ?

37. Reactions of Substitution—Displacement

We have already got acquainted with two types of chemical reactions : (1) reactions of decomposition and (2) reactions of combination.

In the decomposition reaction (page 32) two or more substances are obtained from one substance, whereas in the reaction of combination (page 35) two or more substances produce one new substance.

The reaction between zinc and hydrochloric acid for obtaining hydrogen can be shown as :

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Hydrochloric acid}}{2HCl} = \underset{\text{Zinc chloride}}{ZnCl_2} + \underset{\text{Hydrogen}}{H_2}$$

(Two substances) (Two substances)

In this reaction, the number of substances taken is the same as the number of substances produced. One of the reactants (initial substances), zinc, is a simple substance. The atoms of zinc take the place of atoms of hydrogen in the molecules of hydrochloric acid, with the result that a new compound substance—zinc chloride—and a new simple substance—hydrogen—are formed. In other words, zinc atoms substitute hydrogen atoms in the molecules of hydrochloric acid, resulting in the formation of zinc chloride and hydrogen.

Similarly, two new substances, copper and water, are formed as a result of the interaction between hydrogen and copper oxide :

$$\underset{\text{simple substance}}{H_2} + \underset{\text{compound substance}}{CuO} = \underset{\text{compound substance}}{H_2O} + \underset{\text{simple substance}}{Cu}$$

In this reaction, atoms of copper in the molecules of cupric oxide are substituted by hydrogen atoms, as a result of which a new compound substance, water, and a new simple substance, copper, are obtained.

Now let us find out by an experiment whether the atoms of copper present in a compound substance can be substituted by the atoms of other metals.

EXPERIMENT

Dissolve a little copper chloride in water. Take the solution in a test-tube or a porcelain basin. What is the colour of the solution? Now put a clean iron nail or a little iron powder into the solution and observe what happens. What is the substance that is separated from the solution and gets deposited on the nail, or settles down at the bottom of the test-tube or the porcelain basin ?

Now observe the colour of the solution. Has it undergone any change ? Which substance is present in the solution now ? Write the equation of the reaction that has taken place.

The experiment shows that due to the interaction of iron and copper chloride, substitution of the atoms of copper present in the compound, copper chloride, has taken place by the atoms of iron present in the simple substance, iron. Hence, the atoms of copper are separated from the molecules of the compound, copper chloride, and free copper is obtained. The atoms of iron enter into the composition of the molecules of the compound substance, iron chloride.

$$\underset{\substack{\text{Iron}\\\text{(simple}\\\text{substance)}}}{\mathrm{Fe}} + \underset{\substack{\text{Copper}\\\text{chloride}\\\text{(compound}\\\text{substance)}}}{\mathrm{CuCl_2}} = \underset{\substack{\text{Iron}\\\text{chloride}\\\text{(compound}\\\text{substance)}}}{\mathrm{FeCl_2}} + \underset{\substack{\text{Copper}\\\text{(simple}\\\text{substance)}}}{\mathrm{Cu}}$$

Hydrogen is liberated by placing aluminium foil in hydrochloric acid. Aluminium chloride ($AlCl_3$) is formed in the solution, according to the following equation.

$$\underset{\text{Aluminium}}{\mathrm{2Al}} + \underset{\substack{\text{Hydro-}\\\text{chloric acid}}}{\mathrm{6HCl}} = \underset{\substack{\text{Aluminium}\\\text{chloride}}}{\mathrm{2AlCl_3}} + \underset{\text{Hydrogen}}{\mathrm{3H_2}}$$

The reactions in which atoms present in a simple substance substitute the atoms in the molecules of a compound substance, are called the **reactions of substitution**.

ASSIGNMENT

Write the three equations of the reactions between different metals and hydrochloric acid. Find out how many atoms of hydrogen are substituted by one atom of each of these metals. Determine the valency of these metals in the compounds that are formed. Compare the number of atoms of hydrogen substituted by one atom of the metal with the magnitude of the valency of the metal.

Atoms of different metals substitute different numbers of hydrogen atoms from the compounds of hydrogen. For example, one atom of sodium substitutes one atom of hydrogen ; one atom of zinc substitutes two atoms of hydrogen and one atom of aluminium substitutes three atoms of hydrogen. In these reactions sodium shows a valency equal to one, equivalent to one atom of hydrogen substituted by it. The valency of zinc in zinc chloride is two and the valency of aluminium in aluminium chloride is three. It is seen that each metal atom substitutes the same number of hydrogen atoms as the magnitude of its valency. On the basis of these substitution reaction experiments, a fuller definition of valency can now be given.

Valency *is the property of a given element to combine with a definite number of atoms of another element or to substitute a definite number of atoms of an element in the molecules of compound substances.*

QUESTIONS AND EXERCISES

1. Explain with examples the following reactions :

   (1) Combination, (2) Decomposition and (3) Substitution.

2. Complete the following equations by putting the appropriate coefficients. To what type of reaction do they belong ?

(1) $Fe + HCl \longrightarrow FeCl_2 + H_2$
(2) $Fe_2O_3 + H_2 \longrightarrow Fe + H_2O$
(3) $Al + HCl \longrightarrow AlCl_3 + H_2$
(4) $Cu + O_2 \longrightarrow CuO$
(5) $HgO \longrightarrow Hg + O_2$
(6) $Ag_2O \longrightarrow Ag + O_2$
(7) $Ba + S \longrightarrow BaS$
(8) $Al + S \longrightarrow Al_2S_3$
(9) $Mn + Fe\,S \longrightarrow MnS + Fe$
(10) $Al + CuCl_2 \longrightarrow AlCl_3 + Cu$
(11) $Al + MnO_2 \longrightarrow Al_2O_3 + Mn$

3. Define Valency giving suitable examples.

PRACTICAL ASSIGNMENT

Preparation of hydrogen and testing its properties

Equipment and Reagents : Apparatus for the preparation of hydrogen, spare delivery tubes, corks, spirit lamp, a trough of water, cupric oxide, granulated zinc, hydrochloric acid, and gas jars or test-tubes.

Experiment 1 : Preparation, collection and testing of hydrogen

Assemble the apparatus (Fig. 76) for the preparation of hydrogen and fix it on a stand. Put 8-10 granules of zinc in a test-tube and add hydrochloric acid (one-third of the test-tube) to it. Close the mouth of the test-tube with a cork fitted with a delivery tube. Wait till all the air in the apparatus is expelled, then collect hydrogen in a test-tube and test its purity (Fig. 73). Fill three test-tubes or gas jars with water and invert them in a trough of water. After having made sure that hydrogen coming out of the delivery tube is pure, bring the end of the delivery tube under the mouth of the test-tube or gas jar under water. The gas will displace the water in the test-tubes (or jars) and get filled in them.

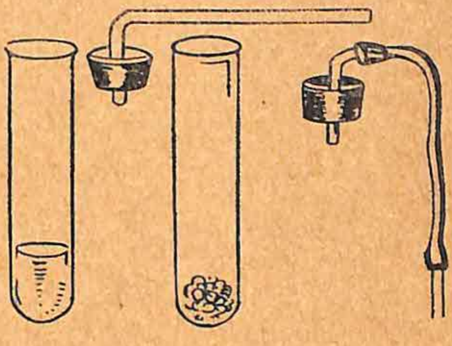


FIG. 76. Apparatus to prepare hydrogen

Experiment 2 : Lightness of hydrogen

(a) Take out from the trough of water two test-tubes (or jars) filled with hydrogen and hold one of them with its open mouth pointed upwards and the other in the opposite direction (*i.e.*, mouth pointed downwards). Hold the tubes (or jars) in the said position for half a minute and then bring them one by one near a flame with the mouth pointing towards the flame. Which one of the two test-tubes (jars) has retained hydrogen? How do you know whether your answer is correct or not? What is the property of hydrogen that is illustrated by this experiment?

(b) Take out the third test-tube (jar) filled with hydrogen from the trough of water and pour the hydrogen from it into a clean, dry test-tube (or jar), by holding the test-tubes (or jars), as shown in the diagram (Fig. 77) and gradually bringing the test-tube (jar) containing hydrogen to a vertical position. Find out which test-tube (jar) now contains hydrogen?

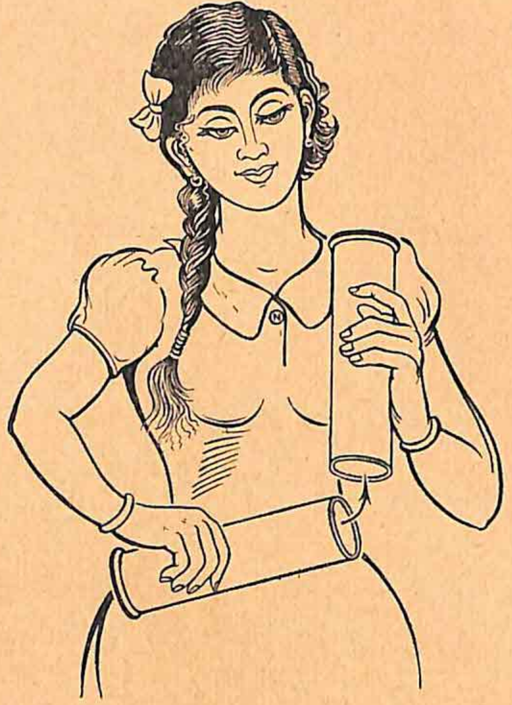


FIG. 77. Pouring hydrogen upwards

Experiment 3 : Reduction of cupric oxide by hydrogen

Take a small quantity of cupric oxide in a dry test-tube. Carefully introduce the delivery tube from a hydrogen generating apparatus into this test-tube containing cupric oxide so that the latter rests on it with its mouth pointing slightly downward. Allow the hydrogen gas to flow into the tube containing cupric oxide. Wait till all the air in the test-tube has been displaced by hydrogen. Now carefully warm the whole test-tube at first and then heat the place where the cupric oxide is placed. As soon as the reduction of cupric oxide is complete, stop heating the test-tube and allow it to cool without removing the delivery tube and stopping the flow of hydrogen.

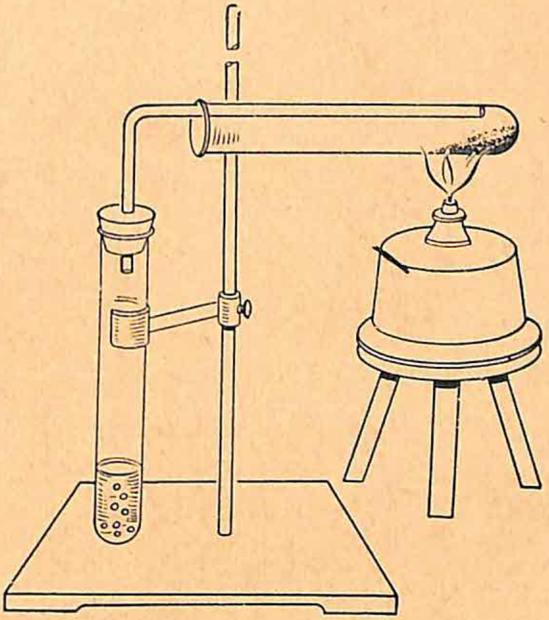


FIG. 78. Reduction of copper oxide by hydrogen

What do you observe on the walls of the test-tube ? What substance is now left behind in the test-tube ? Take out the substance on a piece of paper or in a mortar and grind it by a pestle. What do you notice ?

Prepare a report on the work you have done.

CHAPTER | V

Water and Solutions

38. Properties of Water

Under normal conditions, pure water is a transparent, colourless liquid which assumes a light bluish colour in thick layers. If we fill a tall cylinder with water, place it on a piece of white paper and observe it from above, we can see that water has a light bluish colour. Pure water is a poor conductor of heat and electricity.

Like other bodies, water also decreases in volume on cooling but only up to +4°C. On further cooling, however, the volume of water starts increasing. On freezing, there occurs a sharp expansion in its volume (about 10 per cent) and hence ice is lighter than water and does not sink in it. This phenomenon is of great significance in nature. Thus when temperature drops below the freezing point of water, a layer of ice is formed on the surface of ponds and water reservoirs, and protects it from getting completely frozen. This allows aquatic life to thrive under water even under such conditions. Under normal atmospheric pressure water boils and gets converted to steam at 100°C. The freezing point of water is 0°C. But water can exist in a gaseous condition even at lower temperatures. Ice slowly evaporates during winter. About 30 per cent of the snow that falls, evaporates from the surface of the land.

Chemical properties of water

Water is quite a stable substance and does not decompose on heating as easily as, for instance, melachite or mercuric oxide. Water can however be decomposed, on heating, to give hydrogen and oxygen only at temperatures above 1000°C.

Water reacts with several substances. For example, it reacts vigorously with metallic sodium. Sodium is a soft silvery metal which can be easily cut into pieces with a knife. It is quickly oxidized by atmospheric oxygen on exposure to air, and hence is kept immersed in kerosene oil.

If a small piece of dry sodium (wiped clean of kerosene) is carefully dropped into a test-tube containing some water (Fig. 79), a vigorous reaction takes place, accompanied by the evolution of heat. One can see the sodium piece floating and running hither and thither over the surface of water, gradually decreasing in size and finally disappearing altogether. If a lighted splinter is brought near the mouth of the test-tube, a flash can be seen. From this one can conclude that by the reaction of sodium on water, hydrogen is produced. The equation of the reaction may be written as :

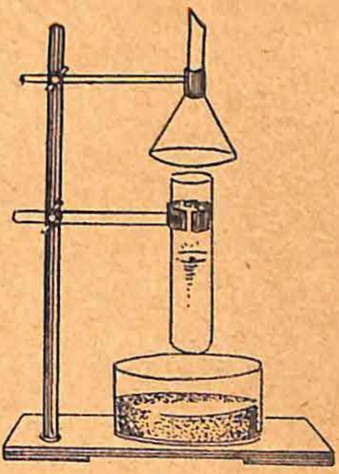


FIG. 79. Reaction of Sodium with water

$$\underset{\text{Sodium}}{2Na} + \underset{\text{Water}}{2H_2O} = \underset{\substack{\text{Sodium}\\ \text{hydroxide}}}{2NaOH} + \underset{\text{Hydrogen}}{H_2\uparrow}$$

A new substance, *viz.*, NaOH, Sodium hydroxide (caustic soda), is formed in the solution, the properties of which you will know later.

All metals are not similar in their reactions with water. Thus zinc and magnesium react actively only with water vapour and that too on heating.

An apparatus which can be used to demonstrate the above reaction is shown in Fig. 80. Powdered zinc or magnesium is heated in the upper part of the test-tube. Water present at the bottom of the tube gets a part of the heat, and starts boiling. The water vapour evolved pass over the heated metal and generate hydrogen which can be collected in a test-tube over water.

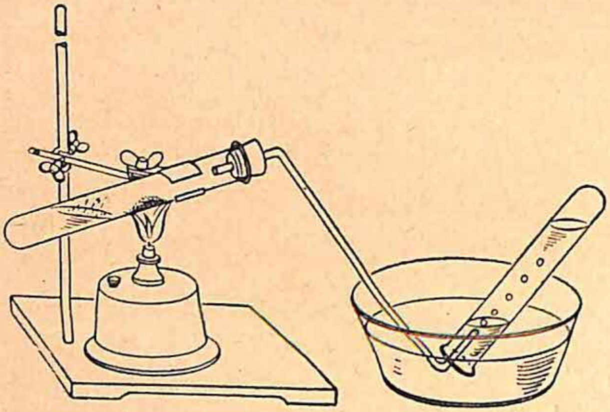


FIG. 80. Reaction of steam with magnesium

The reaction may by represented by the following equation.

$$\underset{\text{Magnesium}}{Mg} + \underset{\text{Steam}}{H_2O} = \underset{\text{Magnesium oxide}}{MgO} + \underset{\text{Hydrogen}}{H_2\uparrow}$$

The second product of the reaction, magnesium oxide, remains behind as a white powder in the test-tube. On strong heating, water vapour reacts with iron also and this reaction is used in obtaining hydrogen on a large scale. The equation for the reaction may be written as follows :

$$\underset{\text{Iron}}{3Fe} + \underset{\text{Steam}}{4H_2O} = \underset{\text{Iron oxide}}{Fe_3O_4} + \underset{\text{Hydrogen}}{4H_2\uparrow}$$

Water also reacts with some non-metals and several other compounds. Water has a great ability to dissolve many substances and this is one of its most important properties, which is of great practical utility. Everyday we come across water solutions called aqueous solutions of various substances in industry and also in our domestic life.

QUESTIONS AND EXERCISES

1. What are the different physical properties of water known to you ?
2. Enumerate the chemical properties of water and indicate how you can verify these properties experimentally.

3. How can you demonstrate the reaction between sodium and water? Write the equation for this reaction.
4. What happens when water reacts with zinc? Under what conditions does the reaction take place? In what way do these conditions differ from the conditions under which water reacts with sodium?

ASSIGNMENT

Read the details of the experiment on decomposition of water by electric current (page 34) and repeat the material given in Sec. 17 (page 53 on the 'Constancy of the Composition of Substances').

39. Qualitative and Quantitative Composition of Water

The composition of water can be determined by docomposing it with the help of an electric current.

This method of determining the composition of a compound by its decomposition is called **analysis.**

You have seen earlier (page 34) that water is made up of two

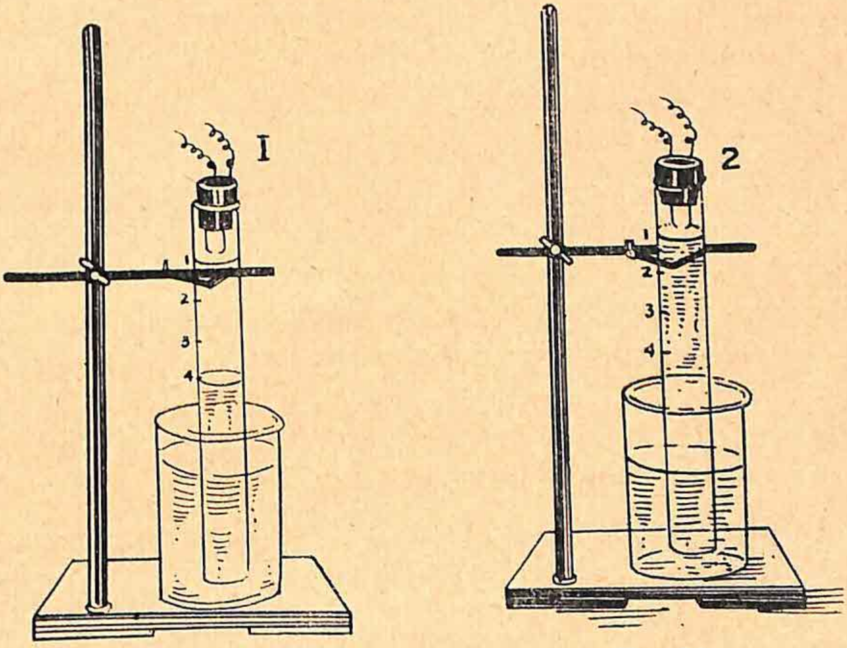


FIG. 81. FIG. 82.

Synthesis of water by electricity

elements, hydrogen and oxygen. This is the *qualitative composition* of water. Further, it can be observed that for every two parts by weight of hydrogen in water there are 16 parts by weight of oxygen which works to 11.11 per cent of hydrogen and 88-89 per cent of oxygen. This is the *quantitative composition* of water.

The same conclusion regarding the composition of water is arrived at, if water is obtained by combining hydrogen and oxygen, *i.e.*, carrying out the synthesis of water.

Synthesis of water is carried out in an apparatus called 'eudiometer'. Eudiometer is a thick graduated glass tube, opening at both the ends, having two wires fixed to its upper end. These wires are either fused in the glass tube or fixed through a rubber cork (Fig. 81). Before the commencement of the experiment, the apparatus is filled with water. Then by displacing water, two volumes each of oxygen and hydrogen are introduced into the tube up to the fourth division mark and an electric spark is passed through the wires. The gas mixture explodes, as a result of which water rises up to the first division mark (Fig. 82). Hydrogen and oxygen combine together to form water.

The volume of liquid water formed is negligible as compared to the volume of the gases from which it is formed and it gets mixed up with the total quantity of water already present in the apparatus. One volume of the gas remains over water in the eudiometer and this can be identified as oxygen by introducing a glowing splinter into the residual gas which bursts into flame.

If we repeat the experiment by taking three volumes of hydrogen and one volume of oxygen in the eudiometer and then explode the mixture, we find that one volume of hydrogen is left behind. Only when we take two volumes of hydrogen and one volume of oxygen, neither of the gases remain after the explosion of the mixture.

Thus it can be seen that hydrogen and oxygen combine with each other in the ratio of 2 : 1, *i.e.*, in the same proportions in which they are obtained by the decomposition of water. The equation of this reaction is written as :

$$2H_2 + O_2 = 2H_2O$$

QUESTIONS AND EXERCISES

1. How do you determine experimentally the qualitative composition of water ?
2. What is meant by the quantitative composition of water ? What does the formula H_2O signify ?
3. Define the terms 'analysis' and 'synthesis'. Describe the synthesis of water in a eudiometer. What does this experiment show ?
4. If a mixture of 10 ml of hydrogen and 8 ml of oxygen is exploded in a eudiometer, which of the two gases will remain after the reaction and what will be its volume ? (Answer : 3 ml of oxygen).

40. Water in Nature : Uses of Water

Of all the compound substances found on earth, water is the most widespread one. 75.8 per cent of the earth's surface is covered by oceans, seas, rivers and lakes. Water not only exists on the surface

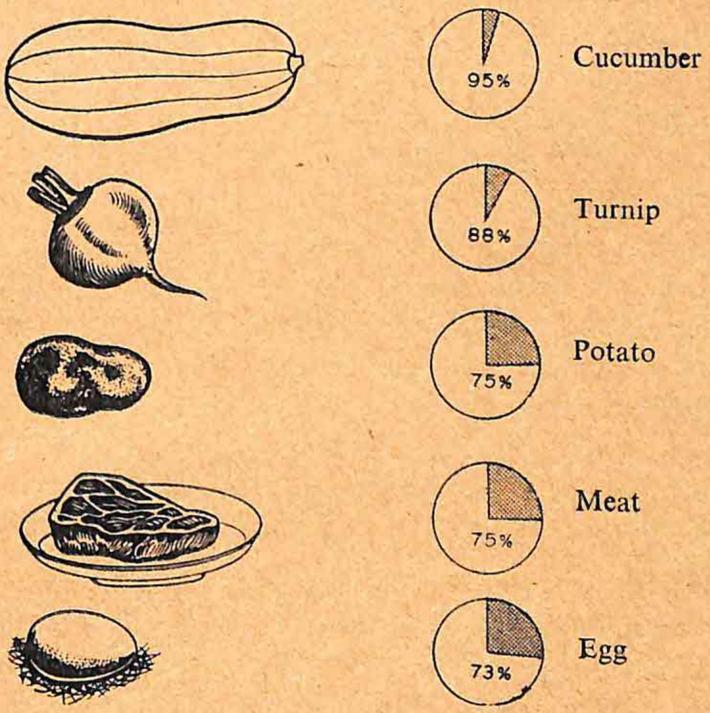


FIG. 83. Amount of water in different food substances

of the earth but is also present in the atmosphere in huge amounts. Thus, air holds nearly 10,000,000,000,000,000 tons of water in the form of vapour, mist and clouds. Furthermore, a lot of water exists in the depths of the earth. One-fifth part by weight of soil consists water. Many foodstuffs have more water contents (Fig. 83). Nearly 65 per cent of the body weight of an adult is water, while in the case of a child it is even larger.

EXPERIMENT

To show that water is present in a few substances which apparently look dry.

Take separately a few dry splinters, pieces of paper and a little soil dried in open air, in three dry test-tubes. Heat them gradually over the flame of a spirit lamp without allowing them to be charred. What do you notice on the upper portion of the walls of the test-tubes?

Though paper, wood and cloth look dry, they give out water on heating. Such water is called **hygroscopic** water. Many substances, for instance, soil, have the ability to hold hygroscopic water and this is one of its most important properties.

By drying substances in a drying oven (Fig. 84) we can determine the quantity of hygroscopic water present in them. By weighing a substance before and after drying it, the quantity of hygroscopic water can be found by taking the difference between the two weights.

A non-stop cycle of water exists in nature. Water evaporates from the surface of the earth, becomes clouds, travels long distances and again pours down to the earth's

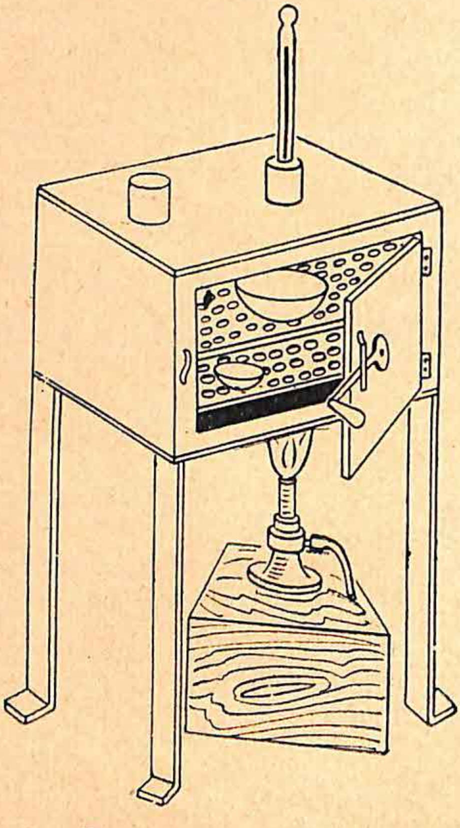


FIG. 84. Drying oven

surface as rain, snow, etc. Thus by virtue of this cycle, water influences the climate to a great extent.

Rocks are split up by water not only mechanically but also chemically by reacting with them. New rocks are also formed by the active assistance of water.

It is well known that neither animals nor plants can live without water. An adult person daily requires at least two litres of water along with his food. Much more water is required for other domestic requirements. It is estimated that the daily average consumption of water per head is about 100 litres in big cities.

Water gives life to the barren lands. The barren lands are being made fertile by spreading network of canals. Irrigation from these canals makes it possible to grow more crops.

Cheap electrical energy can be obtained by tapping the energy of the waterfalls. In India several hydro-electric projects have been set up and many others are in progress, and these play a great role in our national economy.

Water is used as a solvent and also for the production of oxygen and hydrogen in industry. It is also essential in the various branches of metallurgical and fuel industries.

Natural reservoirs of water like rivers and lakes, tanks and canals, must be protected from pollution. If the tail waters from industrial establishments are allowed to mix into these, it will be detrimental to the fish and the water plants. Hence industrial establishments are required to cleanse the waste water before allowing it to flow into these sources. Pollution of water can also be a human health hazard and therefore, it must be prevented at all costs.

QUESTIONS AND EXERCISES

1. Write a few sentences about the distribution of water in nature.
2. What is meant by 'hygroscopic water'? How can you determine the quantity of hygroscopic water in substances?
3. What are the uses of water in technology?

4. Why should the natural reservoirs of water be protected from pollution ?

ASSIGNMENT

Determine the amount of hygroscopic water present in the soil. For this purpose, collect one glass tumblerful of soil from different places in the field of your school plot, spread them in thin layers and allow them to dry up in open air for a few days. Mix the dried soil perfectly well.

Weigh a small porcelain dish on a balance. Put about two teaspoonfuls of powdered soil in the dish and weigh again. The difference in the first and the second weights will give you the weight of the soil taken. Keep the dish containing the soil in a drying oven at a temperature of 105°C for half an hour. Remove the dish from the oven, using a pair of tongs, and place the dish on an asbestos sheet and allow it to cool. Now weigh the dish with the soil again. Do you notice any change in the weight of the soil ? Repeat the heating of the soil on the oven at 105°C for half an hour, cool it and weigh it again. If this weight is the same as the previous weight, then you can consider the experiment to be complete. If there has been a decrease in weight on the second weighing, repeat heating, cooling and weighing of the dish till a constant weight is obtained. From the data collected by you, find out the quantity of hygroscopic water present in the soil. Then calculate how many grammes of hygroscopic water would be present in 100 grammes of soil. This is the percentage of hygroscopic water in your soil sample.

41. Purification of Natural Water

Water found in nature is not completely pure. Several dissolved and suspended impurities are found in it. Fig. 86 shows the quantity of dissolved substances per ton of natural water from different sources. The largest quantity of impurities are found in sea water and hence it has a bitter and saline taste. The smallest amount of impurities are found in rain and snow water. Sometimes dissolved substances having medicinal properties are found in the waters of certain springs. Such waters are called mineral waters, and are used in the treatment of various diseases. Such springs containing sulphur are found in Kangra valley.

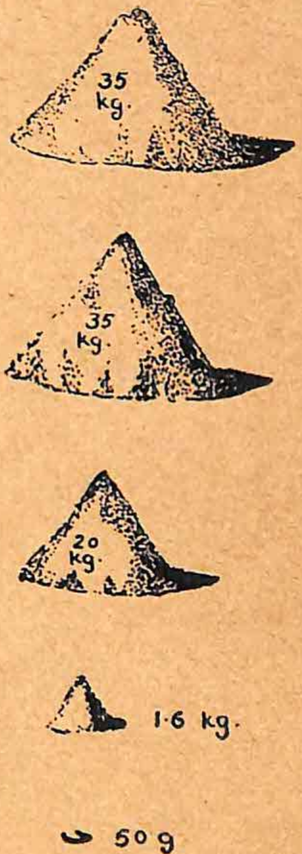
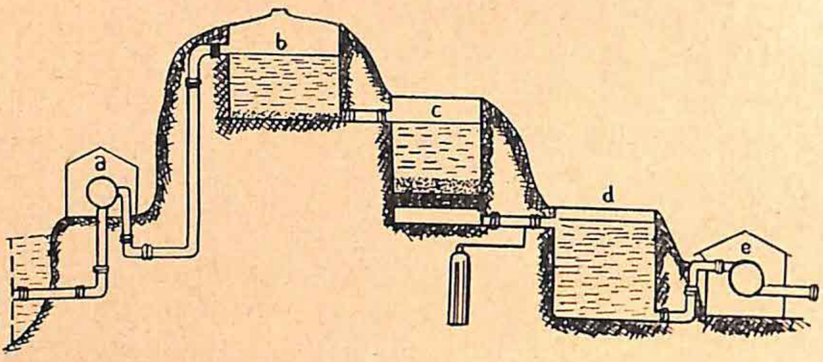


FIG. 85. Amount of soluble substances in water. From top : sea, maximum saline well, lake, river and rain water

River, lake and well waters generally contain dissolved compounds of calcium, magnesium and iron. Water containing such substances is called **hard water.** Soap does not produce much lather with hard water. Water which gives lather easily with soap is called **soft water**. Hard water leaves a scum on the walls of the vessel in which it is boiled. In steam boilers such scum may lead to their bursting. Hard water cannot be used in a number of chemical industries like those for the manufacture of paper, artificial fibres, etc.

Suspended impurities can be separated from water by decantation and filtration. Softening of hard water can be done by adding a little lime or soda to it. Softening apparatus containing absorbers which hold back the dissolved impurities can also be used for the removal of the hardness of water. Water for domestic purposes (for washing clothes, etc.) can be softened by adding a little washing soda to it.

Drinking water must be thoroughly purified. It should be transparent and harmless. In big cities purification of water is done in water-works (Fig. 86) before it is distributed for use. River water is led into sedimentation tank (b) through pipe (a) which is fitted with a gauze, where most of the suspended impurties get settled. Then the water is freed from fine suspended particles by passing it through sand filters (c). The microbes present in water are killed by disinfecting the water chemically, for example, by chlorinating the water in tank (d). Chlorine kills microbes, but is not harmful to human beings when used in small doses. Water thus purified and disinfected is fit for drinking.



a—Pump b—Settling tank c—Filtration tank
d—Disinfection tank e—Supply pump

FIG. 86. Purification of water in a water-works

For certain purposes water needs to be completely freed from the dissolved and other impurities and this can be achieved by the process of **distillation** (Fig. 87). Distillation is employed in chemical laboratories. The apparatus consist of a distilling flask fitted with a cork carrying a thermometer and connected to a Liebigs condenser. The other end of the receiver is connected to an adapter which leads to a receiver in which the purified water is collected. During distillation, cold water enters the outer jacket of the condenser through the lower inlet and leaves it through the upper outlet. On boiling, water is converted into steam, which gets cooled in the condenser and thus gets condensed into water again. This now trickles down into the receiver. All the impurities are left behind in the distillation flask. For instance, if coloured or salty water is subjected to distillation, the distilled water obtained will neither have colour nor the salty taste.

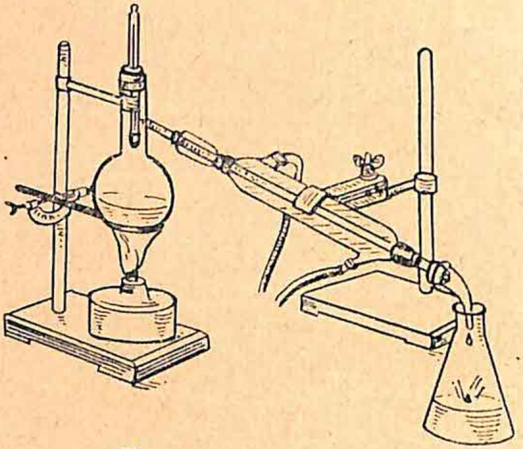
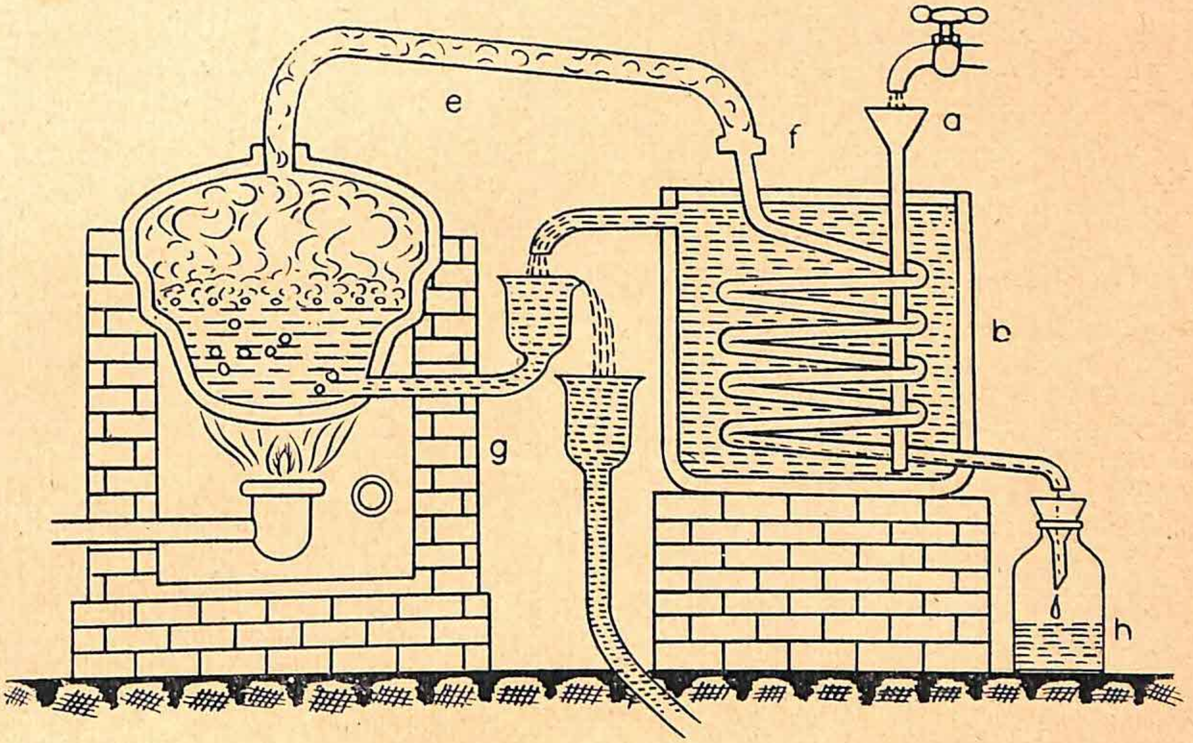


FIG. 87. Distillation

Water purified by the above process is known as *distilled water*. It is used in chemical laboratories, for making solutions in dispensaries, for preparing medicines, in car batteries and for other purposes. It is not used for drinking, since it is insipid to taste. Distilled water is completely devoid of all mineral substances, and its continued use for drinking may cause illness.

For getting large quantities of distilled water, metal boilers heated electrically or by gas, are used for distillation (Fig. 88).



a—Water supply
b—Condenser
c—Retort
d—Boiler

e—Delivery tube
f—Condensing coils
g—Water outlet
h—Receiver

FIG. 88. Distillation plant

Not only water but also other liquids can be purified by distillation, which is one of the most important methods of purification of substances in the laboratories and industrial establishments.

QUESTIONS AND EXERCISES

1. What impurities can you remove from water by decantation and filtration ?
2. What is hard water ? How can it be softened ?
3. What is meant by distilled water ? How can you obtain distilled water in the laboratory ?
4. Rain and snow water are the purest forms of natural water. Explain why.
5. If one litre of water is completely decomposed, what will be the weight of hydrogen and oxygen obtained ? (Answer : 111.1 gms of hydrogen and 888.9 gms of oxygen).
6. If a mixture of 8 ml of hydrogen and 5 ml of oxygen is exploded in a eudiometer during the synthesis of water, which gas will remain after the explosion ? How many ml of it will be left behind ?
7. 250 ml of oxygen is liberated on decomposition of water by an electric current. Calculate how many grammes of hydrogen are liberated in this reaction during the same period. What was the weight of water decomposed to obtain the above ? (1 litre of hydrogen weighs 0.89 gm and 1 litre of oxygen weighs 1.43 gm.)
   (Answer : water decomposed 0.432 gm; hydrogen liberated 0.045 gm).
8. From the formula of water, calculate how much oxygen by weight is present for every 100 parts by weight of hydrogen. (Answer : 800 parts by weight).
9. How many litres of oxygen are required to burn 250 litres of hydrogen ? (1 litre of hydrogen weighs 0.09 gm and 1 litre of oxygen weighs 1.43 gms).
   (Answer : 201.15 gms of water are formed).

42. Solutions

Water dissolves many substances but all substances do not dissolve in it. Howsoever much we may shake clay, sand, oil or kerosene with water, they do not dissolve. Instead, a turbidity is formed by the solid particles or minute droplets of liquid which remain suspended in water. Such a mixture is called **suspension**. On allowing the liquid to stand for some time, the particles that give rise to turbidity gradually settle at the bottom or float on the surface. It is this property that is made use of in the separation of mixtures by decantation (page 19).

Substances like common salt, saltpetre, sugar, copper sulphate, nitre, etc., behave in a manner different from the above. They dissolve in water and form solution. Such substances are called **soluble** substances. These solutions have properties quite different from those of the suspended particles.

Solutions, whether they are colourless or coloured, are perfectly transparent. Even with the help of a microscope we cannot see the particles of the dissolved substance. Howsoever long the solution may be allowed to stand still, the dissolved substances do not separate out.

Now let us find out experimentally what happens when substances are dissolved in water.

EXPERIMENT

Fill three glass cylinders with clear water. Put a little powdered sand in one of them, a few large crystals of blue coloured copper sulphate into the second and a few pieces of orange coloured potassium dichromate into the third. Allow the cylinders and their contents to stand still and observe the phenomena taking place. In the first cylinder the sand particles gradually settle down at the bottom and no solution is formed. In the second, a blue coloured solution of copper sulphate is formed. The dissolved copper sulphate starts rising up from the bottom of the cylinder and soon the whole of the liquid in the cylinder acquires a uniform blue colour of copper sulphate. The solution becomes perfectly homogeneous after a few days. The same process takes place in the third cylinder as in the case of the second, the only difference being that the colour of the solution is orange instead of blue.

Let us see how we can explain the process of dissolution on the basis of atom-molecular studies.

In the case of solids, the molecules are attracted strongly towards one another and hence they cannot move freely in all directions. But when a soluble substance comes into contact with water, the attraction between the molecules becomes less and hence these molecules separate from the surface of the substance and enter into solution. It means that dissolution of a substance in water involves the breaking up of the substance into molecules and greater freedom of movement. Molecules in a solution can move freely in all directions due to which the molecules of the soluble substances mix up with those of the molecules of water which are also in motion. This fact can explain the phenomenon of diffusion in solutions which you have learnt earlier (See pages 3-6).

Sand is insoluble and its particles are not broken into molecules in water. Even the most minute particle of sand is made up of a very large number of molecules. Such particles do not have the freedom of movement of their own as the molecules of soluble substances have and hence they settle down at the bottom of the vessel due to the force of gravitation.

The study of solutions is of immense importance to many branches of science. A large number of chemical reactions are carried out in solutions. Minerals are extracted from soil by plants in the form of solutions. We eat a variety of food stuffs in the form of solutions. Solutions have great practical significance in different industries.

In our daily life we come across not only water as a solvent but spirit, petrol, acetone and other liquids are also used as solvents for different substances.

QUESTIONS AND EXERCISES

1. Quoting examples from nature, explain what is meant by a suspension. What are the properties of suspensions that you have learnt ?
2. Enumerate the differences between solutions and suspensions that you know.
3. What are the properties of solutions that you have learnt ?

4. What is meant by the term diffusion ? What is its significance in the process of dissolution ? How can the phenomenon of diffusion be explained on the basis of atom-molecular theory ?

43. Solubility of Solid Substances in Water

How much of a solid substance can be dissolved in a definite quantity of water, say, 100 ml. This can be determined on the basis of the following experiment.

EXPERIMENT

Take a beaker containing 100 ml of water, add to it 10 gms of powdered common salt and stir with a glass rod. The whole of the salt dissolves after some time. If a fresh quantity of 10 gms of salt is added to the above and stirred again, it will also dissolve completely. A third portion of salt, again 10 gms when added and stirred, will also dissolve completely but slowly. If the process is repeated, *i.e.*, if we add another portion of 10 gms of salt, a part of it remains undissolved at the bottom of the beaker even after the most vigorous stirring. It means that one cannot go on dissolving a substance endlessly and that there is a limit to the amount of the substance that can be dissolved in a given quantity of a solvent. From this experiment it has been observed that about 35 gms of common salt can be dissolved in 100 ml of water at room temperature, after which the solution becomes saturated and no more salt can be dissolved.

A solution in which a given substance stops dissolving further at a fixed temperature is called **saturated solution**.

We can obtain a saturated solution of potassium nitrate at room temperature by dissolving 35 gms of it in 100 ml of water, whereas one can get a saturated solution of potassium chlorate, under the same conditions by dissolving only 7 gms of the substance in 100 ml of water. But it will be necessary for us to dissolve 200 gms of silver nitrate in 100 ml of water, if we want to prepare a saturated solution of silver nitrate at room temperature.

Thus, it follows that the solubility of different solid substances in water varies. Some substances dissolve only to such a small extent on shaking them with water, that it becomes rather difficult to find out whether their solutions have been formed at all.

EXPERIMENT

Let us find out by experiment whether plaster of paris dissolves in water or not. For this purpose, take about 0.5 gm of powder in a test-tube containing 10 ml of distilled water. Close the test-tube with a stopper and shake it vigorously for some time. Can you find out by looking at it whether any plaster of paris has gone into solution or not ? Now filter a part of the turbid liquid into a clean test-tube, and evaporate a few drops of the transparent filtrate on glass plate by holding it high over a flame. What do you observe ? Does any residue remain on the plate ? Is plaster of paris soluble in water ? About 0.2 gm of plaster of paris dissolves in 100 ml of water. Lime dissolves even less. The lime-water that you have come across is a saturated solution of lime, 100 ml of which contains only 0.16 gm of lime. Thus you can see that lime is practically insoluble in water. If powdered chalk is stirred in water and after filtration a few drops of the filtrate are evaporated on an iron or glass plate, no trace of it can be seen on the plate.

All substances are divided into soluble, partially soluble and practically insoluble, according to their solubility in water.

Examples of soluble substances are common salt, saltpetre, copper sulphate, silver nitrate, potassium chlorate, etc. Partially soluble substances are lime, plaster of paris, etc. Practically insoluble substances are chalk, sand, glass, etc.

We cannot observe discernible solution of substances like chalk, glass, etc., by the usual methods (evaporation of filtrate). However even such substances dissolve in water in very small quantities. No substance is absolutely insoluble. Even metals like gold and silver, for instance, dissolve in water though in an insignificant amount. If water is kept in a silver vessel or if a silver object is put in water, the microbes present in water get killed, and such water can be served for a long time. It does not rot, nor does it acquire a bad taste. People did not understand the cause of this phenomenon till it was shown by later studies that insignificant quantities of silver get dissolved in water and kill the microbes, thus preventing the rotting of impurities in it.

Now let us find out by an experiment whether a substance dissolves in hot and cold water to the same extent or not.

EXPERIMENT

Prepare a saturated solution of potassium nitrate in water by taking a test-tube filled with water to a quarter of its capacity and adding small amounts of potassium nitrate and shaking it till no more of the salt dissolves. Now carefully heat the test-tube. What do you observe ? Add a little more of the salt and heat again. What is the conclusion that you can draw from this experiment ?

Now place the solution containing the hot nitrate solution in a beaker of cold water. What do you observe ? Why does it happen ?

It has been shown that as much as 240 gms of potassium nitrate can be dissolved in 100 ml of water at 100°C, while at room temperature only 33 gms can be dissolved in the same quantity of water.

In the cases of potassium chlorate, copper sulphate and alum also, the same thing happens.

The solubility of a majority of substances increases with the increase in temperature.

There are however some substances whose solubility does not increase significantly with the increase of temperature. For instance, take the case of common salt. 35 gms of common salt dissolve in 100 ml of water at 20°C, while in the same quantity of water at 100°C only 39 gms (*i.e.*, 4 gms more) of salt can be dissolved.

QUESTIONS AND EXERCISES

1. What is meant by saturated solution ? How can you prepare a saturated solution of common salt in water ?

2. How can you divide solid substances on the basis of their solubility ? Give examples to illustrate your answer.
3. Prove that plaster of paris and lime are partially soluble in water.
4. Has the temperature any effect on the solubility of solid substances in water ? If it has, show that in what way the solubility is influenced by it.
5. Explain what happens if solutions of saltpetre and copper sulphate saturated at 50°C are cooled down to the room temperature ?
6. How can you convert (a) a saturated solution to an unsaturated solution and (b) an unsaturated solution to a saturated one ?

Growth of Crystals

You must have observed that when a hot saturated solution of saltpetre is cooled, the salt separates in the form of needles and not in the form of a fine powder. Similarly, on cooling a hot saturated solution of copper sulphate, the salt gradually separates in the form of regular polygonal prisms.

Separation of a solid substance from a solution is called **crystallization**.

In this process, substances separate in the form of crystals of different shapes. The formation of crystals shows that the molecules in a solid substance are not arranged in any random manner, but are in a definite order.

From small crystals one can obtain larger ones. Thus a crystal of copper sulphate can be made to grow by suspending it in a saturated solution of copper sulphate. The saturated solution of copper sulphate can be prepared by dissolving 30 gms of the substance in 100 ml of water. The beaker is carefully heated to a temperature of about 60°C over an asbestos gauze, while the solution is being kept stirred. If the solution is allowed to cool gradually by placing the beaker containing the solution for a night, the next day crystals of copper sulphate can be seen at the bottom of the beaker while the solution above will be saturated.

Filter the saturated solution into a clean beaker. Then select a small crystal of copper sulphate from among the crystals formed and tie it with a string. Tie the other end of the string to a glass rod. Dip this crystal in the saturated solution of copper sulphate by resting the rod on the beaker and let it stand. The growth of the crysta can be watched and the expansion in its dimensions noted every four to five days.

Similarly, grow the crystals of alum, dichromate and common salt and make a collection of crystals.

44. Solubility of Liquids and Gases in Water

Besides solids, liquids and gases also dissolve in water.

EXPERIMENT

To test the solubility of spirit in water

Take a test-tube filled with water to a fourth of its capacity (about 5 ml), add to it about 2 ml of spirit and shake it well. Again, add 2 ml of spirit and shake. Can you distinguish the spirit from water ? Do you obtain a saturated solution in this case ?

Take another test-tube containing about 5 ml of spirit, add about 1 ml of water to it and shake. Does it dissolve ? What is dissolved in what when spirit is added to water ? Was it spirit that dissolved in water or was it water that dissolved in spirit ?

Similarly, find out the solubility of kerosene oil in water. Compare the results of the two experiments given above.

Depending on their ability to dissolve in water, all liquids are divided into soluble, partially soluble and insoluble ones. Any amount of spirit dissolves in water. It does not form a saturated solution. Many other liquids like sulphuric acid and nitric acid, also dissolve in water quite well.

A liquid that is partially soluble in water is ether. If a small quantity of this liquid is added to water, it goes into solution. But if more ether is added, it does not dissolve, but gets separated as a layer from the water. Thus a saturated solution is obtained.

There is mutual dissolution of liquids. Thus if you add spirit to water, spirit dissolves in water, and water also dissolves in spirit. Ether and water, however, form saturated solutions with each other.

Vegetable oils and kerosene oil are partially insoluble in water. Nor does water dissolve in them.

Among gases, some are very soluble in water. For example, ammonia and hydrogen chloride. One litre of water can dissolve as much as 1000 litres of gaseous ammonia. A water solution of ammonia gas is called *liquor ammonia* and a solution of hydrogen chloride is called *hydrochloric acid.*

Most gases have a poor solubility in water. For instance, only about 30 ml of oxygen dissolves in one litre of water, while nitrogen has a considerably lower solubility than even oxygen. Hydrogen and inert gases are examples of those gases that are partially insoluble in water.

EXPERIMENT

To determine whether water contains any dissolved air

Take a test-tube and fill it with fresh cold water. Close its mouth by a finger and invert it in a beaker of water (Fig. 89). Holding the test-tube with a test-tube holder or rolled paper, carefully heat the bottom of the test-tube. Where does the air expelled from water collect ? In what way does the solubility of air in water depend on temperature ?

Solubility of gases in water sharply decreases with the increase in temperature.

Because of this, on heating water, the air dissolved in it is liberated. The quantity of air dissolved in water can be determined by heating water in a flask and by collecting the air liberated in a test-tabe (Fig. 90). Boiled water does not contain any air, and hence fish cannot live in it. But if such water is kept open for sometime, air dissolves in it again.

Solubility of gases in water increases with the increase in pressure.

In the manufacture of aerated waters, carbon dioxide is dissolved in water under pressure. One can see the dissolved carbon dioxide escaping rapidly, on opening a bottle of aerated water. The aerated water looks as if it were boiling.

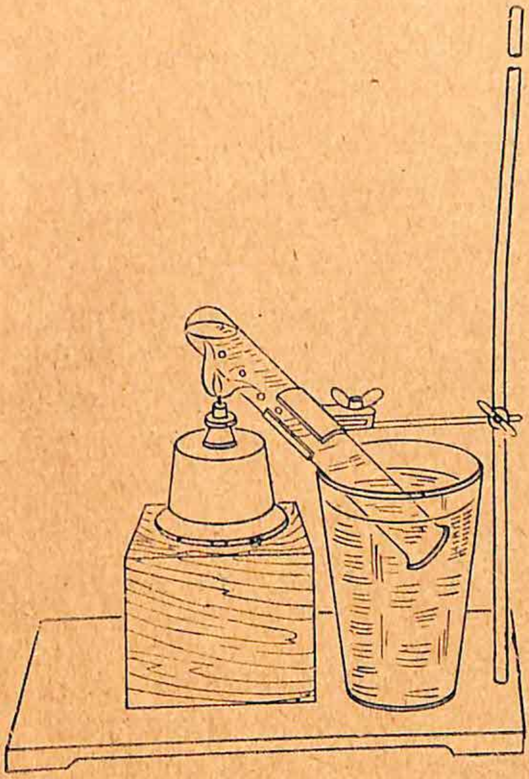


FIG. 89. Solubility of air in water

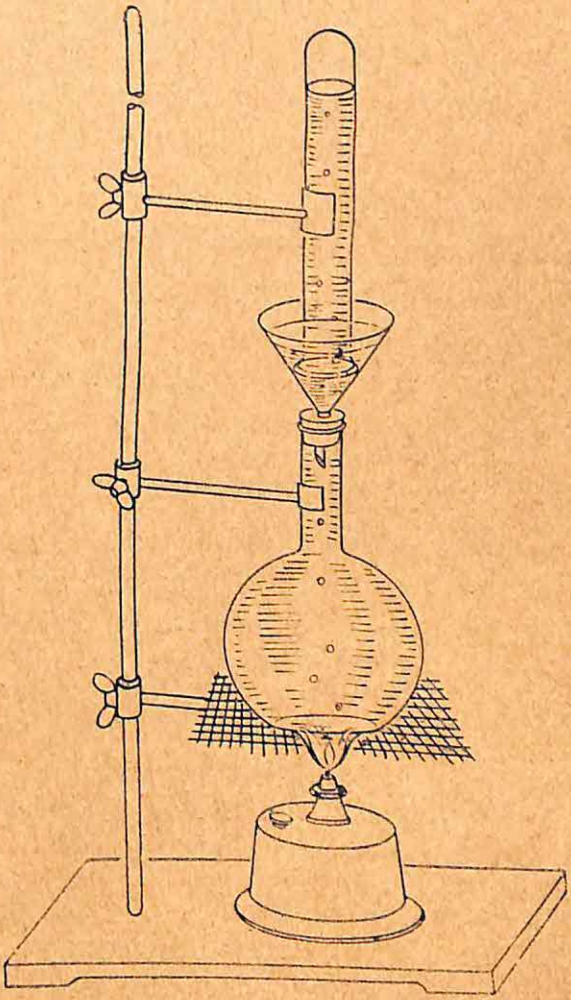


FIG. 90. Determining the quantity of dissolved air

QUESTIONS AND EXERCISES

1. In what manner are liquids and gases divided according to their solubility in water ? Can all liquids

form saturated solutions in water ? Give examples in support of your answer.

2. Enumerate the instances of gases, soluble and partially soluble, in water.
3. Why is it necessary to pump air through water in the aquaria ?
4. In what manner does the solubility of gases depend on temperature ?
5. How can you prove the presence of dissolved air in water ?
6. On opening a bottle of aerated water, liberation of carbon dioxide takes place. Why ?

45. Concentration of Solutions

For practical application of solutions it is of utmost importance to know how much of any dissolved substance (sometimes referred to as the solute) is present in a given quantity of a solution. Such a quantity of the substance is known as the *concentration of the solution.*

> *Concentration of a solution is that quantity by weight of a dissolved substance, which is present in a definite quantity of the solution.*

It is customary to express the concentration of solutions in percentage. Concentration in percentage indicates how many parts by weight of a dissolved substance are present in 100 parts by weight of the solution. If, for instance, 100 gms of a solution contain 20 gms of a dissolved substance, the concentration of this solution will be 20 per cent. For preparing such a solution, 20 gms of the substance are dissolved in 80 gms of the solvent.

Now, suppose we want to calculate the concentration of a solution containing 15 gms of a substance dissolved in 100 gms of water. In percentage, we must find out the quantity by weight of the dissolved substance present in 100 gms of the solution. Let us see how it is done.

Weight of substance dissolved = 15 gms
Weight of solvent (water in this instance) = 100 gms
Weight of the solution = weight of solvent + weight of solute
= 100 + 15 = 115 gms

Now 115 gms of solution contain 15 gms of solute.

$\therefore$ 1 gm ,, ,, $\frac{15}{115}$,, ,,

$\therefore$ 100 gms ,, ,, $\frac{15 \times 100}{115} = 13.04$,, ,,

Thus the concentration of the solution in percentage = 13.04 per cent

Let us now take another example. For getting a 10 per cent aqueous solution of a substance, we should take 10 gms of the substance for every 90 gms of water. Suppose we have to prepare a 10 per cent aqueous solution. What are the weights of solute and solvent (water in this case) that we have to take ?

In 100 gms of solution we have 10 gms of solute.

$\therefore$ In 500 ,, ,, ,, ,, $\frac{10 \times 500}{100} = 50$ gms

Hence, water to be taken = 500—50 = 450 gms

Therefore, we should take 450 gms of water and 50 gms of solute if we are to prepare 500 gms of a 10 per cent aqueous solution of the solute.

Now calculate how many grammes of the substance are present in 250 gms of a 12 per cent solution.

100 gms of a 12 per cent solution contain
12 gms of the dissolved substance.

$\therefore$ 250 gms of a 12 per cent solution will contain $\frac{12 \times 250}{100}$
= 30 gms of dissolved substance.

If both the constituents of a solution are liquids, the concentration of such solutions is usually expressed in terms of the volume of the solvent and that of the solute (liquid). Thus, for example, a solution of sulphuric acid in laboratories is often prepared by dissolving one volume of the acid in five volumes of water. The concentration of such solutions is expressed in the ratio 1 : 5 (1 of acid to 5 of water).

The concentration of partially soluble substances and certain poisonous substances is expressed as 1 : 2000, which means that one part by weight of the substance is dissolved in 2000 parts by weight of water or any other solvent.

> *A solution that contains much of the dissolved substance, is called a* **concentrated solution.** *A solution that has only a small quantity of the dissolved substance, is usually called a* **dilute solution**.

QUESTIONS AND EXERCISES

1. Define the 'concentration of a solution'.
2. What are the methods of expressing concentration of solution that you know ?
3. Calculate the percentage concentration of a solution of common salt, if 20 gms of it are dissolved in 100 ml of water. (Answer : 16 per cent).
4. If 250 gms of potassium nitrate are dissolved in 1 litre of water, what is the percentage concentration of the solution ? (Answer : 20 per cent).
5. If you are to prepare a 15 per cent aqueous solution with 200 gms of potassium nitrate, how much water should be taken ? (Answer : 1133 ml of water).
6. What is the weight of common salt that should be dissolved in 300 ml of water to obtain a 5 per cent solution of it ? (Answer : 15.8 gms).
7. If 300 ml of water is added to 500 gms of a 10 per cent solution of copper sulphate, what will be the percentage concentration of the new solution ? (Answer : 6.25 per cent).
8. What is the weight of sulphuric acid present in 300 gms of a 10 per cent solution ? (Answer : 30 gms).
9. If, after evaporating 50 gms of a solution of common salt to dryness, 5.8 gms of it are left behind. What

was the percentage concentration of the solution ?
(Answer : 11.6 per cent).

10. What is the percentage concentration of a solution that is obtained, if 180 gms of it were left behind after evaporation of a part of the water from 250 gms of a 5 per cent solution of copper sulphate ?
(Answer : 7 per cent).

11. One ton of sea water contains 35 kg of dissolved substances. What is the percentage concentration of a solution of the dissolved substances ? (1 ton : 1000 kg.) (Answer : 3.5 per cent).

12. Given that 1 litre of hydrogen chloride weighs 1.63 gms, what will be the percentage concentration of solution containing 100 litres of hydrogen chloride in 1 litre of water ? (Answer : 14 per cent).

13. The following substances form solutions at room temperature in the proportions given below. Calculate the percentage concentration of each of the solutions :

(a) Common salt : 88.5 gms in 250 ml water
(b) Potassium nitrate : 15.8 ,, ,, 50 ,, ,,
(c) Alum : 12 ,, ,, 200 ,, ,,
(d) Potassium chlorate : 74 ,, ,, 1000 ,, ,,

Answers : (a) 26 per cent, (b) 24 per cent,
(c) 5.6 per cent and (d) 6.89 per cent.

PRACTICAL ASSIGNMENT

Preparation of solutions

Equipment and reagents : balance, measuring cylinder, bottles for solutions, common salt, potassium nitrate, potassium chloride, soda.

Experiment 1 : To calculate the weights of the two substances required to prepare 200 gms of a 5 per cent solution of common salt and to prepare it. Weigh the calculated quantity of the salt by means of a balance. The required quantity of water is measured in a cylinder and transferred to a solution bottle. The weighed salt is now added to it and stirred till the whole of it is dissolved. Prepare a label as shown below and paste it on the bottle.

common salt
5 per cent solution

Experiment 2 : To prepare a potassium chloride solution. Three gms of potassium chloride are dissolved in 50 ml of water. The solution is transferred to a bottle. Calculate the percentage of the solution. The label on the bottle should show the name of the solution and its percentage concentration.

Experiment 3 : To prepare a solution of soda and to bottle and label it. Five gms of soda are dissolved in 100 ml of water. The solution is then transferred to a bottle. The percentage concentration of the solution is calculated and is shown on the label pasted on the bottle, along with the name of the solution.

CHAPTER VI

Oxides, Bases, Acids and Salts

Substances can be divided into simple and compound on the basis of the composition of their molecules. Simple substances can be further divided into metals and non-metals.

Oxides, for instance, are included in 'compound substances'. You are already familiar with some of them. Besides oxides, bases, acids and salts have considerable importance in chemistry. We shall now study the properties of these classes of substances.

OXIDES

46. Oxides of Non-metals

Let us now study in detail the properties of some oxides of non-metals already familiar to us.

Carbon dioxide (CO_2) : Carbon dioxide is a colourless, odourless gas which is one-and-a-half times as heavy as air. In nature, it is continually being formed during burning, breathing, decaying and fermentation of substances. It is also formed in the interior of the earth and in volcanic eruptions. Furthermore, it is found dissolved in the water of various mineral springs.

It is known to you that carbon dioxide does not support combustion of many substances. Man and animals cannot live in an atmosphere of this gas.

Carbon dioxide can be prepared in the laboratory by the action of hydrochloric acid on marble.

Take a few pieces of marble in a test-tube and add dilute hydrochloric acid to a third of its capacity. Close the test-tube with a cork fitted with a delivery tube. Pass the gas evolved into a test-tube containing lime water and show that it turns turbid, thereby proving that the gas formed is carbon dioxide. Kipp's apparatus may also be used to prepare carbon dioxide.

Let us now examine some of the chemical properties of carbon dioxide.

Pass the gas through water containing a few drops of a violet solution of litmus (a vegetable dye). The colour of litmus turns red by this reaction. It is known that acid solutions have the property of changing the violet colour of litmus to red. Therefore, as a result of the solution of carbon dioxide in water, an acid is formed. This is carbonic acid.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} = \underset{\text{carbonic acid}}{H_2CO_3}$$

Another characteristic property of carbon dioxide is its ability to react with lime water and turn it turbid (milky). The reaction can be represented as follows :

$$\underset{\substack{\text{Carbon}\\ \text{dioxide}}}{CO_2} + \underset{\text{Lime water}}{Ca(OH)_2} = \underset{\substack{\text{Calcium}\\ \text{carbonate}}}{CaCO_3} + \underset{\text{Water}}{H_2O}$$

Sulphur dioxide (SO_2) : Sulphur dioxide is also a colourless gas with a pungent odour and is heavier than air. To find whether any reaction takes place between water and sulphur dioxide, pour some water containing a few drops of a violet solution of litmus into a jar containing sulphur dioxide, produced by burning sulphur in oxygen. The violet colour of litmus turns red. Therefore an acid is formed by the interaction between sulphur dioxide and water.

$$\underset{\text{Sulphur dioxide}}{SO_2} + \underset{\text{Water}}{H_2O} = \underset{\text{Sulphurous acid}}{H_2SO_3}$$

Phosphorus pentoxide or *Phosphoric anhydride* (P_2O_5) : This white crystalline substance is obtained by burning phosphorus in oxygen (page 67). Put a little phosphoric anhydride into a little water, contained in a beaker. It rapidly goes into solution with a hissing noise accompanied by the liberation of a large quantity of heat.

When you test the solution with a violet solution of litmus, the colour of the latter changes to red. It follows that in this case also the interaction between water and the oxide of the non-metal produces an acid in solution.

Many other oxides of non-metals also react with water (which is a characteristic reaction for these) to form acids, which turn violet solution of litmus to red. Only very few oxides of non-metals (for example, silicon dioxide or sand, SiO_2) are there which do not react with water.

47. Oxides of Metals

Let us now study the properties of some oxides of metals. We shall begin with calcium oxide which is widely used. It is also known as quicklime.

Calcium oxide (CaO): Calcium oxide (quicklime) is a white solid. Let us see if it reacts with water. Take a few pieces of calcium oxide in a dish and add water to it, drop by drop. A vigorous reaction between the two takes place producing a large amount of heat (Fig. 91). The substance produced as a result of the above reaction is called *slaked lime*. Dissolve the powder, thus obtained, in water and filter the liquid. Take a small quantity of the filtrate and add some violet litmus solution to it. The colour of the litmus turns blue. Take some more quantity of the above filtrate and add a few drops of a colourless solution of phenolphthalein. It turns pink.

FIG. 91. Pouring water on quicklime

Solutions of bases have the property of changing the violet colour of litmus solution to blue and the colourless solution of phenolphthalein into pink.

Therefore one can say that as a consequence of the interaction of calcium oxide and water, a new substance, called a base is formed in solution.

Some other oxides of metals, for example, sodium oxide, potassium oxide and barium oxide, also react with water to form basic solutions exhibiting similar properties as those shown by the solution of calcium oxide in water.

Do all the metallic oxides react with water ? For example, do the black powder of copper oxide and the brown powder of iron oxide react with water ? Add a small quantity of water to each of these oxides in two test-tubes, shake well and filter. Divide the filtrates into two parts each and test the two parts with litmus and phenolphthalein respectively. It will be observed that no change of colour takes place in these two cases. Furthermore, if a drop of each of the two filtrates is evaporated on a watch-glass, no residue is left behind. From this experiment we find that black copper oxide and brown iron oxide do not react with water, nor do they dissolve in it.

We can thus come to the conclusion that the oxides of some metals react with water to give substances known as bases. Examples of this type are oxides of calcium, barium, sodium and potassium. Another type of oxides, for example, those of copper, iron, etc., do not react with water. Many other oxides of metals also do not react with water.

48. Preparation of Oxides

Many oxides can be obtained by the direct combination of simple substances with oxygen. We have seen in Chapter III how oxygen reacts with magnesium, sulphur, charcoal and phosphorus with the formation of magnesium oxide (MgO), sulphur dioxide (SO_2), carbon dioxide (CO_2) and phosphorus pentoxide (P_2O_5), respectively (pages 66-68).

Many oxides can also be obtained by the decomposition of complex substances, for instance, copper oxide is obtained by heating malachite (page 32).

49. Production of Quicklime

Calcium oxide (quicklime) finds wide use in industry. Large amounts of calcium oxide are used in producing slaked lime or mortar which is used as a building material and for whitewashing buildings.

In industry, slaked lime is obtained by baking limestone which contains calcium carbonate, $CaCO_3$. Two compounds, calcium oxide and carbon dioxide, are produced on baking limestone.

$$CaCO_3 \overset{\text{baking}}{=} CaO + CO_2$$

A temperature of 1200°C is best suited for giving good results. This is attained by burning coke mixed with limestone. The mixture of initial materials is called a *charge* in technology. Lime kilns are used for baking. A kiln is a furnace constructed with ordinary bricks and lined inside with fire proof bricks (Fig. 92). The charge of limestone and fuel is fed through the upper opening called the *feeding funnel* (a). To ensure simultaneous and complete baking, the pieces of limestone and coke should be of uniform size, (about 10 cm in diameter). In some cases a gaseous fuel which gives higher temperatures is used in place of a solid fuel. Air, which is necessary for combustion, is let in through the lower part of the kiln (c).

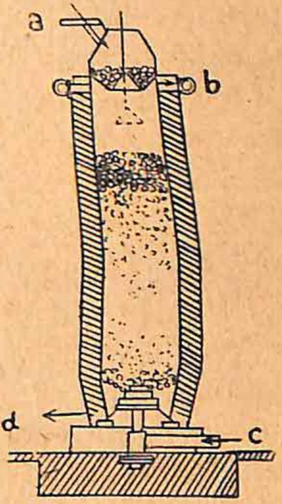


FIG. 92. Limestone kiln
a—Feeding funnel
b—Gas outlet
c—Air inlet
d—Outlet for solids

The kiln is heated up by the heat supplied by the hot gases on their way upwards. The outgoing gases have a temperature of over 2000°C. These gases, produced during the burning of the fuel at the lower parts of the kiln, get relatively cooled on their upward journey. The limestone decomposes giving lime and carbon dioxide. The quicklime falls into the lower part of the kiln. It gets cooled by the incoming cold air which gets heated in this process.

There is an opposite movement of gases and solid materials taking place in the lime kiln. Limestone, solid fuel and the lime produced move downward while the carbon monoxide and carbon dioxide produced during the burning of the fuel move upward. This opposite movement of the initial and resultant materials is known as *counter-current*. Owing to this counter-current the outgoing gases get cooled and the charge gets heated during its downward journey. The use of the heat of certain substances in the heating of others is called *heat exchange*. The principles of counter-current and heat exchange are also utilized in many other industrial processes.

QUESTIONS AND EXERCISES

1. What are oxides ?
2. Write the equations for the reactions by which the following oxides can be obtained : (a) Lithium oxide, Li_2O ; (b) Zinc oxide, ZnO and (c) Aluminium oxide, Al_2O_3.
3. Which of the following oxides has the highest percentage of oxygen ? (a) calcium oxide (b) cupric oxide (c) sulphur dioxide and (d) phosphorus pentoxide.
4. How is calcium oxide produced industrially ?
5. By what chemical reaction can you distinguish between calcium oxide and phosphoric anhydride ?
6. Which oxides of metals (a) react with water, (b) do not react with water ?

BASES

Let us now study the properties of some of the bases, the most important of which are caustic soda and slaked lime.

50. Caustic Soda—NaOH

Observe the sample of caustic soda (sodium hydroxide) supplied to you. How does it look ? Find out if it is soluble in water, by putting a few pieces of caustic soda in water contained in a test-tube and stirring it with a glass rod. **(Do not touch caustic soda but use a pair of tongs or forceps)**. Hold the test-tube in your hand. What do you experience ? Keep the solution so obtained and perform the following experiments.

Place a piece of caustic soda on a glass plate and leave it there for some time. What happens to it ? Divide the caustic soda solution prepared above into 3 parts in 3 test-tubes. To one of them, put a piece of cloth. To the second add 2-3 drops of colourless phenolphthalein solution, and to the third add a small quantity of a violet solution of litmus. What do you observe in each case? What are your conclusions?

Sodium hydroxide (caustic soda) is a white solid readily soluble in water. The dissolution of caustic soda in water is accompanied by the liberation of large quantities of heat. Solid caustic soda deliquesces in open air, since it absorbs the moisture present in air and interacts with carbon dioxide. Concentrated solutions of caustic soda destroy vegetable and animal tissues and hence great care should be taken while handling caustic soda and its solutions. It will cause deep and painful burns, if it falls on the human skin.

If solid caustic soda or its solution falls on the skin or clothes, the affected part should be washed with water at once. It is better to use a one per cent solution of boric acid

Litmus solution is coloured blue and phenolphthalein solution is coloured pink on addition of caustic soda. Sodium hydroxide is commercially called caustic soda. It has extensive uses in industry. Large amounts are utilized in the production of soap, in refining petroleum products and in the production of artificial silk, etc.

Sodium chloride (common salt) serves as the raw material for the manufacture of caustic soda. It is obtained by the electrolysis of a solution of common salt.

Another base named potassium hydroxide (caustic potash, KOH) has similar properties. This white solid is readily soluble in water. The solution of potassium hydroxide (KOH) also turns the colourless solution of phenolphthalein to pink and the violet solution of litmus to blue.

51. Slaked Lime (Calcium Hydroxide)—$Ca(OH)_2$

Calcium hydroxide is a white powder partially soluble in water. Its aqueous solution is called lime water. It turns the colour of litmus to blue and makes phenolphthalein pink, as does sodium hydroxide. It is obtained by the reaction of calcium oxide with water. The reaction is accompanied by the evolution of a large quantity of heat.

$$CaO \quad + \quad H_2O \quad = \quad CaO_2H_2$$

The formula CaO_2H_2 is usually written as $Ca(OH)_2$.

The reaction of combination of substances with water is known as hydration (from 'hydro' meaning water). The products of this reaction are called *hydrates* or *hydroxides*. Thus the product obtained by reaction of calcium oxide and water is called calcium hydroxide. Similarly, caustic soda is also called sodium hydroxide, since it could be obtained by the combination of sodium oxide and water.

Calcium hydroxide obtained by the hydration of calcium oxide is very important to industry. This process is known as slaking of lime and calcium hydroxide is called slaked lime.

Slaked lime finds a variety of uses in many branches of national economy. Large amounts of slaked lime are used in the production of mortar. Slaked lime is also used in many branches of production in place of caustic soda which is costlier.

A solution of slaked lime in water is called lime water. You have learnt that it is turned milky by carbon dioxide. This is due to the formation of the insoluble white solid called calcium carbonate.

$$\underset{\substack{\text{Calcium}\\ \text{hydroxide}}}{Ca(OH)_2} \quad + \quad \underset{\substack{\text{Carbon}\\ \text{dioxide}}}{CO_2} \quad = \quad \underset{\substack{\text{Calcium}\\ \text{carbonate}}}{CaCO_3} \quad + \quad \underset{\text{Water}}{H_2O}$$

52. Cupric Hydroxide—$Cu(OH)_2$ and Ferric Hydroxide—$Fe(OH)_3$

EXPERIMENT

Observe carefully the sample of cupric hydroxide given to you and describe its physical properties.

Take a little cupric hydroxide in a test-tube, add water to a third of its capacity and shake well. Does cupric hydroxide dissolve in water?

After cupric hydroxide settles down, add 2-3 drops of phenolphthalein to the test-tube. Do you observe any change of colour?

Next, take a little cupric hydroxide in a dry test-tube and heat it mildly over a flame. State what do you observe and what substances are obtained as a result of the reaction.

Cupric hydroxide is a blue solid practically insoluble in water, unlike the bases we have studied so far. It decomposes into copper oxide and water on slight heating.

$$Cu(OH)_2 \xrightarrow{\text{heat}} CuO + H_2O$$

But the reverse of the above reaction, *i.e.*, combination of copper oxide and water to form copper hydroxide, does not take place. In other words, cupric oxide does not take part in the reaction of hydration.

Ferric hydroxide, $Fe(OH)_3$ is a brown solid. Like cupric hydroxide it is also insoluble in water and decomposes into ferric oxide and water on heating.

$$2\,Fe(OH)_3 \xrightarrow{\text{heat}} Fe_2O_3 + 3\,H_2O$$

In this case also the reverse reaction does not take place.

All the metallic hydroxides studied by us can be classified under the name of *bases*. Sodium hydroxide, NaOH ; Potassium hydroxide, KOH ; Calcium hydroxide, $Ca(OH)_2$; Cupric hydroxide, $Cu(OH)_2$; Ferric hydroxide, $Fe(OH)_3$ are all examples of bases.

53. The Composition of Bases

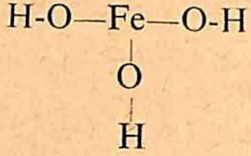
All bases are composed of oxygen and hydrogen atoms in addition to atoms of metals. For example, sodium hydroxide molecules are expressed by the formula Na—O—H. The dashes between the symbols of the atoms are used to represent the valency of the elements in the compound. In a molecule of caustic soda a sodium atom is connected with an oxygen atom which is also connected with a hydrogen atom.

A molecule of calcium hydroxide consists of one calcium atom and two atoms each of oxygen and hydrogen. Its formula $Ca(OH)_2$ can be expressed as shown below :

H-O—Ca—O-H

A molecule of sodium hydroxide and a molecule of calcium hydroxide, both have a similar group or combination of atoms attached to a metal atom. This group consists of an atom of oxygen and an atom of hydrogen. It cannot exist independently, but is present in the molecules of compounds and is known as the *hydroxyl* group. The valency of the hydroxyl group ($-OH$) is equal to one.

Since sodium is always monovalent in all the compounds, there will be only one OH group in sodium hydroxide. The valency of calcium in its compounds is two and hence in a molecule of calcium hydroxide there are two hydroxyl groups. Similarly, iron has a valency 3 in ferric hydroxide ; hence, ferric hydroxide has 3 hydroxyl groups in its molecule and its formula can be expressed as



$$\begin{array}{c} H\text{-}O-Fe-O\text{-}H \\ | \\ O \\ | \\ H \end{array}$$

There are several other substances whose molecules have one or more hydroxyl groups attached to the atom of the metals. These substances are all known as bases.

> **Bases** *are those compounds whose molecules hold atoms of metals connected with hydroxyl groups.*

The number of hydroxyl groups present will depend upon the valency of the metal present in the base.

Bases are divided on the basis of their solubility in water. Sodium hydroxide, $NaOH$, Potassium hydroxide, KOH, Calcium hydroxide, $Ca(OH)_2$ and a few other bases are soluble in water and these are called *alkalis*. Since they destroy animal and vegetable tissues, they are often called *caustic alkalis*. Caustic soda, caustic potash, etc., are examples. The alkalis are characterized by their ability to change the colour of substances like litmus (violet or red to blue) and phenolphthalein (colourless to pink) and a few others in their aqueous solutions.

Alkalis can be obtained by the combination of metal oxides and water and hence may be termed as the products of hydration of oxides.

The majority of bases are insoluble in water. Examples are cupric hydroxide and ferric hydroxide. They cannot therefore be obtained by the hydration of oxides. On heating they get decomposed giving water and the oxide of the metal concerned. For example :

$$Cu(OH)_2 \xrightarrow{heat} CuO + H_2O$$

Hence they are called hydroxides. Hydroxides are substances that can be obtained by the hydration of oxides and also substances which, on decomposition, form an oxide and water.

QUESTIONS AND EXERCISES

1. What are the physical and chemical properties of caustic soda ?
2. What are the uses of caustic soda ?
3. What is lime water ?
4. What are the substances that can be classified as bases ?
5. What are alkalis ?
6. How can you distinguish sodium hydroxide from ferric hydroxide ?
7. Determine the valency of the metals in the following bases :

   KOH, $Ba(OH)_2$, $Cu(OH)_2$, $Fe(OH)_3$
8. Write the equations of the reactions that take place in the following changes.

   $$Ca \rightarrow CaO \rightarrow Ca(OH)_2$$

ACIDS

54 Sulphuric Acid—H_2SO_4

Sulphuric acid, a heavy oily liquid is sold in the form of a 96-98 per cent aqueous solution. The specific gravity of such an acid solution is 1.84.

To study the solubility of sulphuric acid in water, we shall proceed as follows :

Take a beaker of water and carefully pour sulphuric acid into it in a thin stream. A thermometer placed in the water contained in the beaker shows a sharp rise in the temperature. This shows that the dissolution of sulphuric acid in water is accompanied by the liberation of a considerable quantity of heat.

When water is poured into sulphuric acid, the first portion of water moves upwards, since it is lighter than the acid. This part gets heated by the heat produced during dissolution, and the temperature may even reach 100°C and above. At this temperature some of the water is converted into vapour. This vapour forces itself outside taking with it splashes of the acid. It may cause severe *injury to a person if it comes in contact with his body. Hence, as* a rule, water must not be poured into sulphuric acid. This rule **should be strictly observed**. On the contrary, sulphuric acid should be added to water carefully in a thin stream mixing up the contents of the vessel by means of a glass rod.

Sulphuric acid absorbs moisture from the air and hence it is used as a drying agent. If a wooden splinter is put in a beaker containing concentrated sulphuric acid, it is found to get charred after a little time. Concentrated sulphuric acid chars many organic substances. For example, paper, wood and sugar are converted into charcoal by the action of concentrated sulphuric acid which withdraws the elements of water from them.

If sulphuric acid falls on the skin, cloth or footwear, it should be washed away immediately with a strong jet of water and then with a solution of washing soda and again with water.

On intense heating, sulphuric acid is decomposed into sulphur trioxide (also called sulphuric anhydride) and water.

$$\underset{\substack{\text{Sulphuric}\\ \text{acid}}}{H_2SO_4} \xrightarrow{\text{heat}} \underset{\text{Water}}{H_2O} + \underset{\substack{\text{Sulphur trioxide}\\ \text{(sulphuric anhydride)}}}{SO_3}$$

By the interaction of sulphuric anhydride and water, sulphuric acid which is a hydrate of this oxide (sulphuric anhydride) is obtained.

$$\underset{\substack{\text{Sulphuric}\\ \text{anhydride}}}{SO_3} + \underset{\text{Water}}{H_2O} = \underset{\substack{\text{Sulphuric acid}\\ \text{(hydrate of sulphur}\\ \text{trioxide)}}}{H_2SO_4}$$

Anhydrides *are those oxides which on hydration form acids or which can be obtained as a result of the decomposition (dehydration) of acids.*

When we add the violet solution of litmus to sulphuric acid solution, it turns red. A colourless solution of phenolphthalein does not acquire any colour when added to an acid solution.

Litmus, phenolphthalein and some other substances which change their colour by the action of acids or alkalis are called **indicators**.

Litmus or litmus paper is often employed for detection of acids. Litmus paper is a sheet of unsized paper soaked in a solution of litmus.

55. Reaction of Neutralization

Sulphuric acid reacts, among other things, with bases.

EXPERIMENT

Take 25 ml of caustic soda solution in a beaker and add a few drops of a violet solution of litmus to it. It turns blue. Now add a solution of sulphuric acid from a burette into this solution. A burette is a graduated glass tube with a stopper or a pinchcock. The solution is added drop by drop from the burette into the beaker till the solution becomes violet again. This happens when the solution contains neither acid nor alkali. Note the volume of the acid added. It is clear that the acid added has fully reacted with the alkali present. The resulting solution in the beaker containing neither acid nor alkali is known as a *neutral solution.*

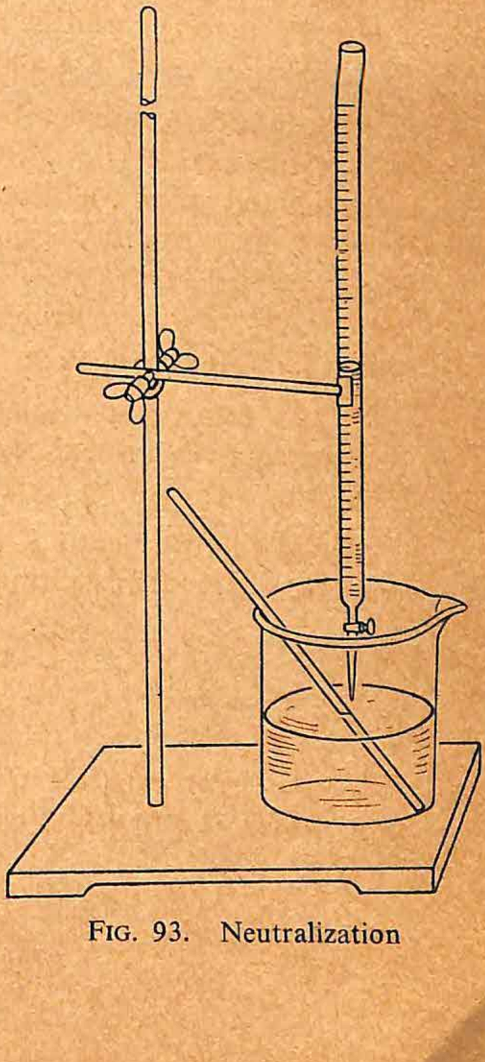


FIG. 93. Neutralization

From the graduations on the burette the volume of the solution of the acid required to react with alkali can be found out. Repeat the experiment without the addition of the indicator. For this purpose, take 25 ml of alkali and add to it by means of the burette the same volume of acid as was required in the above experiment. Now whether or not any indicator was used, we can say with certainty that in this case also a neutral solution will be obtained. To verify this, take small amount of the solution and add a little violet solution of litmus. It will be seen that its colour does not change.

Evaporate a few drops of this resultant solution on a glass plate. A white crystalline substance is left on the glass plate.

This substance was produced as a result of the reaction between the acid and the base. It is called sodium sulphate having the formula Na_2SO_4 and belongs to the class of compounds known as *salts*. The reaction by which this salt is obtained may be represented as

$$\underset{\text{Base}}{2NaOH} + \underset{\text{Acid}}{H_2SO_4} = \underset{\substack{\text{Salt}\\ \text{(sodium sulphate)}}}{Na_2SO_4} + \underset{\text{Water}}{2H_2O}$$

The reaction between an acid and a base, due to which salt and water are formed is called *neutralization*. In this case an acid and a base neutralize each other and the substances formed resemble neither the acid nor the base.

Take a saturated solution of calcium hydroxide (known generally as limewater), add a few drops of phenolphthalein to it and then go on adding a solution of sulphuric acid from a burette, till the phenolphthalein is rendered colourless. It will be observed that the solution in the beaker turns turbid during this process, due to the formation of a salt—calcium sulphate, $CaSO_4$. As it is only slightly soluble in water it settles down slowly at the bottom. Thus in this case also a salt and water are formed by the interaction of an acid and a base.

$$\underset{\substack{\text{Calcium}\\ \text{hydroxide}}}{Ca(OH)_2} + \underset{\substack{\text{Sulphuric}\\ \text{acid}}}{H_2SO_4} = \underset{\substack{\text{Calcium}\\ \text{sulphate}}}{CaSO_4} + \underset{\text{Water}}{2H_2O}$$

Acids and bases have the characteristic property of being able to take part in the reaction of neutralization. This reaction is of great practical utility in determining the quantity of an acid or an alkali in a solution.

56. Nitric Acid—HNO_3

Nitric acid is a colourless liquid readily soluble in water. Its specific gravity is 1.52. It turns violet litmus into red.

Conduct the following experiment in order to study the interaction between nitric acid and a base:

EXPERIMENT

Take a solution of caustic potash in one beaker and 0.5 gm of cupric hydroxide powder in another beaker. Add 3-4 drops of colourless phenolphthalein to the first beaker and by means of a pipette (Fig. 94) go on adding a solution of nitric acid till the pink colour of the solution disappears. Similarly, add nitric acid solution, drop by drop, to the other beaker till the entire cupric oxide reacts giving a light blue solution which, on evaporating in a dish, gives blue crystals of a salt—copper nitrate, $Cu(NO_3)_2$.

From the above experiment we can conclude that nitric acid, like sulphuric acid, takes part in the reaction of neutralization with a base.

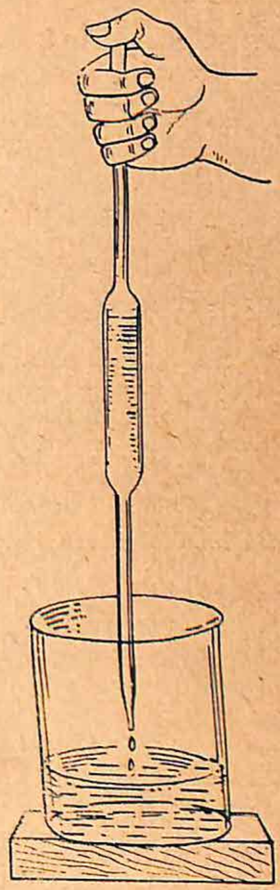


FIG. 94. A pipette

$$\underset{\substack{\text{Base}\\\text{(Potassium}\\\text{hydroxide)}}}{KOH} + \underset{\text{Nitric acid}}{HNO_3} = \underset{\substack{\text{Salt}\\\text{(Potassium}\\\text{nitrate)}}}{KNO_3} + \underset{\text{Water}}{H_2O}$$

$$\underset{\substack{\text{Base}\\\text{(Cupric hydroxide)}}}{Cu(OH)_2} + \underset{\text{Nitric acid}}{2HNO_3} = \underset{\substack{\text{Salt}\\\text{(Copper nitrate)}}}{Cu(NO_3)_2} + \underset{\text{Water}}{2H_2O}$$

57. Hydrochloric Acid—HCl

Hydrochloric acid, a colourless liquid having a pungent odour, is an aqueous solution of the gas, hydrogen chloride. The concentrated

59. Salts of Sulphuric Acid

Sodium Sulphate, Na_2SO_4 : Sodium sulphate is found in nature mostly as a solution. Natural sodium sulphate is called *mirabilite.*

This is a white crystalline substance readily soluble in water. In the natural salt 10 molecules of water are combined to each molecule of Na_2SO_4 and hence its composition is expressed by the formula $Na_2SO_4 . 10H_2O$. Large quantities of sodium sulphate are used in the glass and paper industries. It is also used in medicine under the name of Glauber's salt.

Calcium Sulphate, $CaSO_4$: Another salt of sulphuric acid is calcium sulphate. In nature it is found in the form of gypsum, having the formula $CaSO_4.2H_2O$. Large deposits of gypsum are available in Rajasthan. Calcium sulphate in the form known as plaster of paris is employed in making moulds for various objects and also for obtaining the building material called alabaster. Its formula is expressed as $2CaSO_4.H_2O$. It is also employed in the production of dry plaster.

Blue vitriol (copper sulphate), $CuSO_4.5H_2O$: Observe the crystals of blue vitriol. Take 2-3 crystals in a dry test-tube and hold it tilted towards its mouth. Then heat it over a burner and observe what happens.

After allowing the test-tube to cool, add a few drops of water to the white powder obtained, and observe what happens.

Blue vitriol is a blue crystalline substance having the formula $CuSO_4 . 5H_2O$. Each molecule of the salt contains 5 molecules of water. On heating it, water separates and settles in the form of drops on the cooler parts of the test-tube. It is because of this, that the test-tube contining $CuSO_4$ was heated in this manner. In this position the water formed will not come into contact with the hot parts of the test-tube, and break it. On heating the blue crystals of copper sulphate, a white powder having the formula $CuSO_4$ is formed. As is evident from the formula, this substance does not contain any water. When water is added to it, it combines with water to form the blue crystal of blue vitriol ($CuSO_4.5H_2O$) again.

Water present in the composition of crystals is called **water of crystallization**.

Many salts contain water of crystallization.

Blue vitriol is used for the control of various diseases and crop pests. It is not usually found in nature. It is manufactured in factories from various types of copper waste.

Green vitriol, $FeSO_4 . 7H_2O$ *:* Green vitriol, $FeSO_4 . 7H_2O$ is a bright green crystalline solid, readily soluble in water. It is manufactured by the action of dilute (20-30 per cent) sulphuric acid on scrap iron. Green vitriol is used in the manufacture of mineral dyes, in dyeing cloth and also for controlling crop pests.

60. Salts of Nitric Acid

EXPERIMENT

Study samples of sodium nitrate, potassium nitrate and calcium nitrate, and state what you have observed. Find out by experiment whether they are soluble in water.

Sodium nitrate or *Chile saltpetre :* Sodium nitrate or Chile saltpetre, $NaNO_3$ is found in the form of big natural deposits in only one place in the world and that is in the South American Republic of Chile, and hence its name.

This white crystalline substance is extremely soluble in water. Industrially it is obtained from other sodium compounds. It is mainly used as a fertilizer.

Potassium nitrate, KNO_3. Only a very small quantity of potassium nitrate, KNO_3, is found in nature. It is obtained from other compounds of potassium. It forms white crystals, readily soluble in water. Potassium nitrate finds use as fertilizer and in the manufacture of gun powder, which is a mixture of sulphur, charcoal and potassium nitrate.

Calcium nitrate, $Ca(NO_3)_2$ *:* Calcium nitrate, $Ca(NO_3)_2$, is known as Norwegian saltpetre. Large quantities of it are produced by the neutralization of slaked lime with nitric acid. This is a colourless crystalline substance, readily soluble in water. This substance also finds extensive use as a fertilizer.

61. Salts of Hydrochloric Acid

Sodium chloride (common salt), *NaCl*: It is one of the salts found in nature on a wide scale. It is found in the water of seas and oceans on an extensive scale. In the form of rock salt, its deposits are found in the Salt Range, Panjab. The Sambhar lake in Rajasthan also contains large quantities of sodium chloride.

Common salt finds a variety of uses in day-to-day life and also in industry. It is used as a food preservative (pickling, for instance) and as a condiment in food preparation. It is used in the manufacture of chlorine, caustic soda and hydrogen. It is also used in the production of soda and other substances.

Potassium chloride, KCl: It is a white crystalline substance readily soluble in water. The solubility increases sharply with the increase in temperature. It is an important fertilizer.

62. Composition of Salts

ASSIGNMENT

Write the formulae of the following salts :

Sodium sulphate, sodium nitrate, sodium chloride.

In what way do the molecules of salts differ from the molecules of their corresponding acids ? In what way are the molecules of these salts similar to one another ?

From what we have studied so far, we can draw the conclusion that in the molecules of salts, atoms of metals are joined to acid radicals. Thus the molcules of sodium sulphate contain two atoms of sodium joined to the *sulphate* radical ($-SO_4$). Similarly, in the molecules of sodium nitrate, sodium atoms are connected to *nitrate* radical ($-NO_3$) and the molecules of sodium chloride consist of sodium atoms combined with the acid radical *chloride* ($-Cl$). Thus the molecules of each salt have atoms of a metal and an acid radical.

Salts *are compounds whose molecules have atoms of metals joined to acid radicals.*

For writing the formulae of salts, the following rule must be observed. The total number of valency units of a metal in the molecule of a salt must be equal to the total number of valency units of the acid radical. The molecule of calcium salt of nitric acid—calcium nitrate—has an atom of calcium, the valency of which in a compound is two, and two nitrate radicals (NO_3), each of which contributes one valency unit. Thus the formula of the salt will be $Ca(NO_3)_2$.

In a molecule of aluminium sulphate we have aluminium atoms having a valency 3 and the acid radical sulphate whose valency is equal to 2. The total number of units of valency of the metal can be equal to the total number of units of valency contributed by the acid radicals only, when two atoms of aluminium and three sulphate radicals are present in each molecule of the salt. The formula of this salt, therefore, should be $Al_2(SO_4)_3$.

Oxides, acids, bases and salts are the most important classes of chemical compounds.

QUESTIONS AND EXERCISES

1. What are salts ?
2. What is the common feature of the molecular composition of all the salts of sulphuric acid ?
3. Name the acid radicals present in the following salts : K_2SO_4, $Pb(NO_3)_2$, $CaCl_2$, $AlCl_3$, $BaSO_4$, $Fe(NO_3)_3$.
4. Which has a higher percentage of nitrogen : KNO_3 or $NaNO_3$?
5. Write the formulae of the following substances: Sodium sulphate, Magnesium nitrate, Calcium chloride, Aluminium nitrate and Zinc sulphate.

   To which class of compounds do they belong ?
6. Give the names of the salts of sulphuric acid that you have studied. What are their uses ?
7. What do you understand by 'water of crystallization' ? Write the formulae of two salts containing water of crystallization.

8. What are the substances produced on heating (a) gypsum and (b) green vitriol ?
9. Name the salts of nitric acid that you know and mention their uses.
10. Calculate the percentage composition of sodium chloride (Atomic weight of sodium $=23$ and atomic weight of chlorine $= 35.5$).

    (Answer : Sodium 39.3 per cent ;
    chlorine 60.7 per cent)
11. Where does sodium chloride occur in nature ? In what State is it found ?
12. In which of the following two salts is the percentage of chlorine higher : sodium chloride or potassium chloride ?

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